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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Leapfrog Technology to Standardize Equipment and System Installations

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
National Steel and Shipbuilding Company
San Diego, California

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DISCLAIMER

SECTION NO. 1 — LITERATURE SEARCH AND BENCHMARKING

TABLE OF CONTENTS

SECTION NO. 2 — EQUIPMENT, SYSTEM INSTALLATION, AND TECHNICAL CRITERIA

TABLE OF CONTENTS

LIST OF TABLES

SECTION NO. 3 — DESIGN CRITERIA AND ATTRIBUTES FOR REDUCING COST

TABLE OF CONTENTS

SECTION NO. 4 — BOUND THE PROBLEM

TABLE OF CONTENTS

LIST OF FIGURES

SECTION NO. 5 — ENGINEERING, TESTING, AND VALIDATION METHODOLOGY

TABLE OF CONTENTS

SECTION NO. 6 — MANUFACTURING AND INSTALLATION TECHNIQUES

TABLE OF CONTENTS

SECTION NO.7 — ENGINEERING ANALYSIS AND DEVELOP STANDARDS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION NO. 8 — PRODUCT MODELING CRITERIA AND DEMONSTRATION

TABLE OF CONTENTS

SECTION NOS. 9 AND 10 — REVIEW AND APPROVAL PROCESS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

FINAL REPORT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY NSRP 0537

INTRODUCTION

The objective of this manual is to develop a set of equipment and distributive system installation standards that result in the lowest possible installed cost. These standards are to be parametric in nature and lend themselves to inclusion into a product modeling system.

Traditionally the design of foundations and hangering systems was based on qualitative requirements that have been developed from what is known as “the principles of good sound shipbuilding practices.” Line organizations in most shipyards have been conditioned over the years to ‘properly’ implement the specifications. The basis or rationale for much of the specifications has been lost over time. It is difficult to attempt to initiate changes in design to reduce costs when engineers and designers will not risk departing from traditional ways because they are fearful of violating unknown criteria. Guidance on designs provided by engineering management organizations usually instructs the designer/engineer to use designs developed on prior ships as a basis for new designs. In this way previous designs are perpetuated and little or no innovation is permitted in the development of new designs.

The present technology for designing, manufacturing, and installing equipment foundations and systems is labor intensive and is often on the critical path of ship construction. The lowest total installed costs will be achieved through the streamlining or elimination of these labor-intensive tasks.

Leapfrog Technology is defined within this project as a holistic, cost effective approach to combining and applying innovative yet simple products and processes concurrently throughout various departments including engineering, fabrication shops, and production stages of construction.

By applying leapfrog technology products and processes concurrently throughout all departments within the shipyard, significant reduction of man-hours and construction lead times can be achieved in the area of foundations and hangering systems.

This project will give the tools, products and approach necessary to minimize the completely installed costs for foundations and hangering systems in the form of a manual including ten deliverables, a complete set of standards for foundations and hangers, a scantling selection computer program using Microsoft Excel, and a final report.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 1 — LITERATURE SEARCH AND BENCHMARKING

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TABLE OF CONTENTS

1.A LITERATURE SEARCH AND BENCHMARKING RELATED TO EQUIPMENT INSTALLATIONS

This sub-task report provides a description of the literature search, information collating, and benchmarking performed. Under this task, information and data pertaining to Equipment Installations and Foundations were collected and reviewed. The information collected and reviewed includes the following :

- The existing standards/guidelines for equipment installations of various shipyards
- Rules and guidelines of USCG and ABS
- SSC Reports
- Annual Book of ASTM Standards — Shipbuilding Vol. 01.07
- NAVSEA and Navy General Specification Documents
- Military Standards
- NSRP — Foundation Design Manual
- Foundation Standards for Sealift Ships
- NASSCO’s in-house databases, reports, and documents
- Vibtech’s in-house databases, reports, and documents

The materials collected were reviewed for relevant information applicable to the current project. We evaluated the relevant specifications and existing standards, guidelines, and practices from ship building and other industries. The information was categorized and benchmarked by foundation types and functionality.

NASSCO’s and Vibtech’s in house libraries were thoroughly researched for relevant standards and related information.

These in house libraries produced among others:

- Studs, Spool, and Grillages Analysis for Sealift ships
- PF 109 Class Foundation Design Guide
- Designers Handbook for Foundations, Ingalls Shipbuilding
- Producibility of Foundations, Bath Iron Works
- Foundation Practices Manual, Saint John Shipbuilding
- Foundation Control Plan AOE Class for NASSCO

These standards were extensively reviewed and then collated to accomplish benchmarking. Vender information was also collected and identified from the libraries. This information kept us abreast of new materials and techniques available in commercial form during benchmarking.

1.B LITERATURE SEARCH AND BENCHMARKING RELATED TO DISTRIBUTIVE SYSTEM INSTALLATIONS

This sub-task report provides a description of the literature search, information collating and benchmarking performed. Under this task, information and data pertaining to Distributive System installations was collected and reviewed. The information collected and reviewed includes the following:

- The existing standards/guidelines for system installations of various shipyards
- Rules and guidelines of USCG and ABS
- SSC Reports
- Annual Book of ASTM Standards — Shipbuilding Vol. 01.07
- NAVSEA and Navy General Specification Documents
- Military Standards
- NASSCO's in-house databases, reports and documents
- Vibtech's in-house databases, reports and documents

The process of collecting information pertaining to system installations used in shipbuilding industry as well as other industries is completed. The information has been benchmarked to other standards and collated into a usable form.

Standards have been received from:

- Avondale Shipyard Division
- Kawasaki Heavy Industries, LTD
- National Steel and Shipbuilding Company
- American Society for Testing and Materials (ASTM)
- Saint John Shipbuilding Limited

NASSCO's and Vibtech's in house libraries were thoroughly researched for relevant standards and related information. These in house libraries produced among others:

- Studs, Spool, and Grillages Analysis for Sealift ships
- Pipe Hangers and Cable Hangers Producible Designs
- Medium Weight Testing of Various Stud Weld Attachments
- Analysis of Pipe Hangers for St. John Shipbuilding Ltd.
- Analysis of Spiral Duct Hangers for NASSCO

These standards were extensively reviewed and then collated to accomplish benchmarking. Portions of standards and documents were copied and placed in binders to group like standards in a convenient manner. All of the piping, electrical, and HVAC standards were grouped into individual binders, allowing direct comparisons and ease of reference for the remainder of the work scope. The information/standards arranged by system functionality were further sub-grouped by type, geometry, and fabrication details.

Review of these standards along with shipyard tours to witness first-hand how they apply their particular standards was undertaken. Viewing how standards are applied at the various yards gave us tremendous insite on what should be applied and when, depending on the yard facilities. This benchmarking and compiling of relevant documentation gives us a baseline to proceed with the remainder of the project.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 2 — EQUIPMENT, SYSTEM INSTALLATION, AND TECHNICAL CRITERIA

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TABLE OF CONTENTS

LIST OF TABLES

2.A CRITERIA AND REQUIREMENTS FOR EQUIPMENT INSTALLATIONS

This sub-task report provides a description of the design requirements and engineering criteria to be used in the development of the equipment installation standards.

SHIP MOTION LOADING

The strength of commercial ship foundations is typically governed by accelerations resulting from ship motions in a seaway. Ship specifications typically specify formulas for determining accelerations at different locations on the ship based on heave, surge, roll, pitch, and yaw motions. These "g" values or multiples of the weight to be supported are based solely on ship motions and equipment' location and do not vary with equipment weight or foundation stiffness.

It should be noted that a factor of safety should be used in the design of foundations limited by ship motions. This factor of safety helps ruggedize the foundation against other environmental loads such as pounding, wave slamming, and forces due to weather elements (wind, ice and snow) and helps avoid fatigue-related problems resulting from a design based purely on strength requirements. For combatants the shock induced forces generally produce the greatest load the foundations may experience, thus driving the design requirements, even then cyclic loading, fatigue and other factors may also affect the design of the foundations.

A conservative approach would be to allow the equipment installations to be loaded up to 50% of the material yield strength due to the worst ship motions. Since ship motions typically produce 2-3 times the static load, a foundation designed to this criteria would be able to support at least 4-6 times the static load. In the standards development the seaway loading or the equivalent acceleration values of 3 g's vertical, 1.5 g's transverse and 0.75 g's longitudinal are to be used, simultaneously.

ADDITIONAL LOADS

Equipment installations must be able to support attached equipment and a variety of additional loads and redistribute them into the hull structure. Weights of machinery and equipment, including liquids at operating levels and one half of the unsupported lengths of connected piping and cables, plus the dynamic effects of ship motion and vibration shall be included in the foundation assessment.

VIBRATION

Vibration issues affecting foundation systems are those resulting from hull girder excitation caused by propeller forces on the hull and from deck vibration excitations initiated by unbalanced forces in rotating machinery, structure/machinery resonance conditions or both. Reduction and/or control of structural response to the source of the excitations is essential since excessive vibration can appreciably affect the proper functioning of the supported components, can lead to damage of ship structure, machinery, equipment or systems. Vibration is also a problem when it interferes with personnel safety, comfort or proficiency. Means of preventing excessive vibration during normal ship operating conditions should be anticipated and incorporated in the design and construction of the ship. The correction of a resonance problem in a finished ship can be a very costly and time-consuming effort. There are foundation detail design requirements for vibration that evolve from the specifications and the shipbuilder's plan for implementing the requirements.

The objective of a vibration analysis is to avoid vibratory resonances. The vibratory driving frequencies normally considered include: (1) ship's blade rate, (2) ship's primary hull modes, and (3) machinery rotating speed. An equipment installation should be designed such that its natural frequencies are not in resonance with any of the

driving frequencies. The action of a ship's propeller rotating in a seaway will produce periodic vertical and transverse forces directed at the ship's stern structure. These harmonic forces will excite vibration in the hull at a driving frequency of the rotating rate of the propeller times the number of blades on the propeller. Since the propeller can be rotating at any rate through a range of speeds, the practice has been to design foundations such that their natural frequencies are above the maximum blade rate (maximum shaft revolutions per minute times the number of propeller blades). This criterion need only be applied for foundations located within 1/3 of the length of the ship from the stern since hull structure will tend to dampen the harmonic driving forces and reduce the response amplitudes away from the stern. Typical ship specifications for foundations in the aft 1/3 of the ship require that the foundations and local supporting structure natural frequency should be at least 25% above blade rate. In the forward 2/3 of the ship, caution should be exercised to ensure that foundation frequencies are out of the range of the specified propeller blade operating ranges. In practice there is a low frequency that should be avoided by at least 10% and there is an upper band of frequencies close to blade rate that should be avoided. This results in a fairly wide band between the upper and lower level propeller blade rates within which foundation natural frequencies may be accommodated. However, since the propeller blade rate will pass through these frequencies as power is increased or decreased, there exists the possibility that a transitory resonant condition may exist.

The action of a ship travelling through a seaway will tend to produce harmonic motion of a ship's hull. These motions can be approximated by considering the ship's hull girder as a free-free beam with added mass included to represent the damping effect of the seawater. The resulting natural frequencies and mode shapes are referred to as ship's primary hull modes. It is these hull-driving frequencies which should be avoided in the design of foundations located within the forward part of the ship. Blade rate is usually much higher than any of the primary hull modes and as a result is critical in the aft end of the ship. However, as mentioned above, due to structural damping the blade rate criterion is not critical in the forward length of a ship and as a result the hull mode criterion takes precedence. In designing equipment installations, to avoid resonance with ship's primary hull modes, it is imperative that the mode shape of the driving frequency be considered. The direction of the driving forces for each hull mode will determine which of the foundations natural frequencies should be considered in the criterion. For example, the ship's torsional or rolling mode will have tendency to excite the transverse bending mode of a cantilevered foundation structure mounted to the deck.

The case of a foundation supporting a piece of machinery with rotating parts, which occurs often on board ship, requires an additional vibration criterion. For this situation it is also imperative that a resonance condition does not exist between the machinery's driving frequency and the natural frequencies of the foundation structure. Different criteria exist for units, which are hard mounted, and units, which are resiliently mounted. For hard mounted units it is necessary solely to avoid the machinery's rotating frequency or frequencies, however, for resiliently mounted units it is necessary that all foundation natural frequencies be a factor of 1.25 above the machinery's rotating frequency. The foundation natural frequencies for units which are resiliently mounted are determined by considering the stiffness of the foundation with associated ship's structure and considering solely the mass of the foundation and not of the unit-foundation combination. This is done due to the uncoupling effects of the resilient mounts and to ensure that there is adequate foundation stiffness and mass in way of the mounts.

In case of combatants, the mechanical vibration requirements for all machinery and equipment are typically in accordance with MIL-STD-167. The equipment, as installed, shall not have vibration interference with the operation of the ship's combat system nor degrade the accuracy or sensitivity of the ship's sensors and radar. All limitations, calculations, and analyses for vibration and balancing of electrical, hull, and machinery equipment and components are to be in compliance with MIL-STD-167.

Commercial ship foundations are often more flexible due to the lack of shock requirements. This reduced stiffness and corresponding lower frequency can increase the potential for a vibration problem. However, the situation is helped by the fact that commercial ships typically have a much lower propeller blade rate than combatants. The standards will be developed keeping in mind more of commercial applications.

NOISE

All the equipment installation design requirements for the reduction and control of structure-borne noise are based on the requirements contained in various specifications and identified in various shipbuilders overall silencing plan. The silencing plan considers the established ship noise goals; the contribution of machinery and overall equipment vibration, propeller cavitation and flow noise to the noise levels; the transmission characteristics of the resilient mounts, foundation structures and hull structure. A guide to the implementation of the specific requirements for structure-borne noise reduction and control, which affect foundation design, are generally provided in the Noise Control Program of the specific ship. For combatant ships, structure borne noise requirements are based on operational requirements to reduce and control the radiated noise signature and to decrease the ship's detection susceptibility.

Practical design implications for equipment installations are as follows:

The average stiffness of the support points in way of equipment mounts should be designed to provide a stiffness at least ten times greater than the total dynamic stiffness of the array of mounts resting on it. The dynamic stiffness values of rubber mounts are greater than the static stiffness values used in load-deflection calculations (1.2 to 1.6 x the static stiffness). From a practical standpoint 1/4" to 1/2" plate or angle thickness stiffened with small brackets in way of mount attachments are adequate to meet the dynamic stiffness requirements.

The distribution of mass in a foundation fitted with noise mounts should be such that the mass of the foundation within a periphery of 3" of the mount should be at least 1/50 to 1/100 of the mass supported by the mount.

SHOCK

This criteria is exclusively required for naval combatants only, and therefore is only briefly described for information purpose. An underwater explosion generates a shock wave of intensive pressure, which impinges against the ship hull and induces severe transient motions in the primary hull structure. These motions constitute the shock excitation environment that is transmitted through the hull to the base of the foundation system. The ideal characterization of any underwater explosion and shock excitations is the known time history of the hull shock motion at the structural interface with the foundation. Since such data are not readily available, an alternative approach of either quasi-static analysis method or Dynamic Design Analysis Method (DDAM) is used.

For combatants the shock requirements almost always govern the equipment installation design. Generally the foundations requiring shock qualifications which are not qualified by shock testing are designed for shock in accordance with "Shock Design Criteria for Surface Ships" Publication NAVSEA 0908-LP-000-3010, 1976. Shock design values used for foundation analysis are specified in the Design Data Sheet DDS-072-1 (confidential). These foundations shall be designed using appropriate shock values for location and direction using the allowable stress criteria associated with either the elastic or elasto-plastic design as indicated in NAVSEA 0908-LP-000-3010.

SWAY BRACES & LATERAL SUPPORTS

Shipboard units, which are attached to foundation structure at their base and are fairly tall in comparison to the narrow dimension of their base, pose an additional problem. These units, due to the high position of their center of gravities, will have a tendency to try to overturn about their base. As a result, regardless of the foundation stiffness, the lateral natural frequencies of the structural system will be very low. To prevent vibration excitation and excessive motions of these units it is customary to provide sway braces or any form of lateral

supports at the top of the units. These added supports will eliminate the unit overturning and will raise the system lateral natural frequencies significantly, thus avoiding vibration problems.

HULL INTERFACE AND ACCESSIBILITY

Equipments are generally not supported directly on the shell or other structure exposed to wave impact, propeller excited vibrations, etc., if the resulting distortion or vibration would damage the equipment or limit its performance. Installation members that overhang supporting structure and extend onto deck or bulkhead plating should land on a pad to effect a smooth transition and to reduce the stress in the plating.

Accessibility should be provided for inspection and maintenance of the equipment installation and adjacent hull structure. Foundations should be constructed to avoid pockets, which can contain liquid.

RIGIDITY AND ALIGNMENT

Equipment installations should be rigid enough to ensure that the requirements for limiting twist, bend, level and parallelism with the master datum as specified by equipment manufacturers are met. The rigidity of foundations and supporting structure should be sufficient to prevent misalignment, which would interfere with operation of the machinery and equipment, and to preclude excessive vibratory motion.

Equipment installations should be designed to prevent misalignment or excessive strains due to thermal expansion under all operating conditions.

FATIGUE

Equipment installations subjected to cyclically repeated or reversed loadings should be designed to withstand fatigue. Appropriate rules of classification societies should be consulted to design for fatigue.

CORROSION CONTROL AND PROTECTION

Equipment installations protection and corrosion control requirements should be met during the construction and service life of the ship. Appropriate measures should be taken during the design of foundations to provide access for maintenance and to avoid the effects of corrosion. Treatment of foundations in way of wet and dry spaces, machined surfaces, dissimilar metals, and void spaces must be incorporated in the fabrication and installation process in the proper sequence to achieve preservation and corrosion protection in the most cost effective manner.

ALLOWABLE STRESSES

Under the normal design loads, stresses in steel should not exceed the following allowable limits. These limits are based on allowable criteria generally used for commercial ships; the limits can vary depending on the specifications of specific ships.

Tensile and bending stresses - where there is no danger of failing from instability, allowable limits for the algebraic sums of axial and bending stresses are 50% of material yield strength, as listed in Table 1.

Shear Stresses - where there is no danger from instability, allowable limits for shear stresses are 75 percent of the allowable tensile and bending stress.

For both Elastic and Elastic/Plastic design, the tensile stress in an axially loaded member shall not exceed the material static yield strength.

MATERIAL	NOM. YIELD STRENGTH (KSI)[1]	ELASTIC ALLOWS. STRESS (KSI)	ELASTIC SHEAR STRESS (KSI)	ELASTIC /PLASTIC BENDING STRESS (KSI)[2]	ELASTIC /PLASTIC SHEAR STRESS (KSI)
STEEL					
ORDINARY STRENGTH (OS)	34	17	13	34	26
HIGHER STRENGTH (HS)	51	26	19	51	38
HIGH YIELD (HY-80)	80	40	30	80	60

NOTES: 1) YIELD STRENGTHS FOR STEEL SHALL BE OBTAINED FROM APPLICABLE MATERIAL SPECIFICATIONS.
2) 100% OF NOMINAL YIELD STRENGTH.

Table 1 — Allowable Limits for Foundation Structural Members

Threaded fasteners and hold down bolts requirements for components shall be as defined in the applicable component specification. In case of stud fabricated foundations and stud mounted equipment's the stud allowable stress in bending can be 60% and in shear 45% of its material yield strength, respectively.

The limiting frequency as discussed before should be 1.25 times the maximum propeller blade rate.

2.B CRITERIA AND REQUIREMENTS FOR DISTRIBUTIVE SYSTEM INSTALLATIONS

This sub-task report provides a description of the design requirements and engineering criteria to be used in the development of the distributive systems installation standards.

The criteria and requirements can be categorized into two groups, namely, Global criteria which are applicable to all types of installations, and Specific criteria & requirements applicable to the specific installation type.

Under the **Global** criteria the following requirements are evaluated:

SHIP MOTION LOADING

The strength of commercial ship installations is typically governed by accelerations resulting from ship motions in a seaway. Ship specifications typically specify formulas for determining accelerations at different locations on the ship based on heave, surge, roll, pitch, and yaw motions. These "g" values or multiples of the weight to be supported are based solely on ship motions and systems location and do not vary with system structure weight or installation stiffness.

It should be noted that a factor of safety should be used in the design of installations limited by ship motions. This factor of safety helps ruggedize the installation against other environmental loads such as pounding, wave slamming, and forces due to weather elements (wind, ice and snow) and helps avoid fatigue-related problems resulting from a design based purely on strength requirements.

A conservative approach would be to allow the system installations to be loaded up to 50% of the material yield strength due to the worst ship motions. Since ship motions typically produce 2-3 times the static load, an installation designed to these criteria would be able to support at least 4-6 times the static load. In the standards development the seaway loading or the equivalent acceleration values of 3 g's vertical, 1.5 g's transverse and 0.75 g's longitudinal are to be used, simultaneously.

ADDITIONAL LOADS

System installations must be able to support the attached distributive system and a variety of additional loads and redistribute them into the hull structure. Weights of valves, fittings and connections, including liquids and one half of the unsupported lengths of connected piping and cables, plus the dynamic effects of ship motion and vibration shall be included in the installation assessment.

VIBRATION

Vibration issues affecting installation systems are those resulting from hull girder excitation caused by propeller forces on the hull and from deck vibration excitations initiated by unbalanced forces in rotating machinery, structure/machinery resonance conditions or both. Reduction and/or control of structural response to the source of the excitations is essential since excessive vibration can appreciably affect the proper functioning of the supported components, can lead to damage of ship structure, machinery, equipment or systems. Vibration is also a problem when it interferes with personnel safety, comfort or proficiency. Means of preventing excessive vibration during normal ship operating conditions should be anticipated and incorporated in the design and

construction of the ship. The correction of a resonance problem in a finished ship can be a very costly and time-consuming effort. There are installation detail design requirements for vibration that evolve from the specifications and the shipbuilder's plan for implementing the requirements.

Typical ship specifications for installations in the aft 1/3 of the ship require that the installations and local supporting structure natural frequency should be at least 25% above propeller blade rate. In the forward 2/3 of the ship, caution should be exercised to ensure that installation frequencies are out of the range of the specified propeller blade operating ranges. In practice there is a low frequency that should be avoided by at least 10% and there is an upper band of frequencies close to blade rate that should be avoided. This results in a fairly wide band between the upper and lower level propeller blade rates within which installation natural frequencies may be accommodated.

Commercial ship installations are often more flexible due to the lack of shock requirements. This reduced stiffness and corresponding lower frequency can increase the potential for a vibration problem. However, the situation is helped by the fact that commercial ships typically have a much lower propeller blade rate than combatants. The standards will be developed keeping in mind more of the commercial applications.

NOISE

All the system installation design requirements for the reduction and control of structure-borne noise are based on the requirements contained in various specifications and identified in various shipbuilders overall silencing plan. The silencing plan considers the established ship noise goals; the contribution of machinery and overall equipment vibration, propeller cavitation and flow noise to the noise levels; the transmission characteristics of the resilient mounts, system installation structures and hull structure. A guide to the implementation of the specific requirements for structure-borne noise reduction and control, which affect installation design, are generally provided in the Noise Control Program of the specific ship.

LAYOUT AND SPACING

System layout order and sequence should be established, to allow accurate and efficient installation in a timely and cost-effective manner. Installation spacing is another indirect governing criteria, controlling the weight per installation and thereby controlling the installation members sizing.

HULL INTERFACE AND ACCESSIBILITY

Installation members that overhang supporting structure and extend onto deck or bulkhead plating should land on a pad to effect a smooth transition and to reduce the stress in the plating. The installation attachments to the ship structure should be such that they accomplish a smooth transfer of loads and minimize stress concentrations. Mechanical fastening methods and other alternative attachment techniques should be evaluated.

Accessibility should be provided for inspection and maintenance of the installations, attachments and adjacent hull structure. Installations should be constructed to avoid pockets, which can contain liquid.

FATIGUE

System installations subjected to cyclically repeated or reversed loadings should be designed to withstand fatigue. Appropriate rules of classification societies should be consulted to design for fatigue.

CORROSION CONTROL AND PROTECTION

System installations protection and corrosion control requirements should be met during the construction and service life of the ship. Appropriate measures should be taken during the design of installations to provide access for maintenance and to avoid the effects of corrosion. Treatment of installations in way of wet and dry spaces, machined surfaces, dissimilar metals, and void spaces must be incorporated in the fabrication and installation process in the proper sequence to achieve preservation and corrosion protection in the most cost effective manner.

FASTENING AND WELDING

Fasteners used, as part of the installation should be evaluated for adequacy. Standard mechanical COTS fasteners should be used wherever possible. Welding should comply with ship general specifications or the shipyard welding standards and standard welding details.

ALLOWABLE STRESSES

Under the normal design loads, stresses in steel should not exceed the following allowable limits. These limits are based on allowable criteria generally used for commercial ships; the limits can vary depending on the specifications of specific ships.

Tensile and bending stresses - where there is no danger of failing from instability, allowable limits for the algebraic sums of axial and bending stresses are 50% of material yield strength, as listed in Table 1.

Shear Stresses - where there is no danger from instability, allowable limits for shear stresses are 75 percent of the allowable tensile & bending stress.

For both Elastic and Elastic/Plastic design, the tensile stress in an axially loaded member shall not exceed the material static yield strength.

MATERIAL	NOM. YIELD STRENGTH (KSI)[1]	ELASTIC ALLOW. STRESS (KSI)	ELASTIC SHEAR STRESS (KSI)	ELASTIC /PLASTIC BENDING STRESS (KSI)[2]	ELASTIC /PLASTIC SHEAR STRESS (KSI)
STEEL					
ORDINARY STRENGTH (OS)	34	17	13	34	26
HIGHER STRENGTH (HS)	51	26	19	51	38
HIGH YIELD (HY-80)	80	40	30	80	60

NOTES: 1) YIELD STRENGTHS FOR STEEL SHALL BE OBTAINED FROM APPLICABLE MATERIAL SPECIFICATIONS.
2) 100% OF NOMINAL YIELD STRENGTH.

Table 2 — Allowable Limits for Foundation Structural Members

Threaded fasteners and hold down bolt requirements for certain standard components and fittings on the distributive systems should be defined in the applicable component specification. In case of stud fabricated installations and stud mounted system runs, the stud allowable stress in bending can be 60% and in shear 45% of its material yield strength, respectively.

The limiting frequency as discussed before should be 1.25 times the maximum propeller blade rate.

Under the **Specific** criteria, three major ship-system types, namely, Piping, Electrical/Wireways, and Ventilation/Ducting, categorized the system installations. A fourth category was also established, not based on ship-system, but based on ship-structure interface. This category is installations on Joiner Bulkheads. Specific installation types further elaborated the specific criteria and requirements under each of these major ship-system groups.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 3 —DESIGN CRITERIA AND ATTRIBUTES FOR REDUCING COST

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TABLE OF CONTENTS

3 DESIGN CRITERIA AND ATTRIBUTES FOR REDUCING COST

DEVELOP DESIGN ATTRIBUTES FOR EQUIPMENT INSTALLATIONS

This sub-task report provides the design criteria including producibility features, production and installation techniques for equipment installations, for cost reduction and reduced labor content. These key attributes will facilitate weight and cost reduction through development of standards for foundation design, fabrication and installation.

PRODUCIBILITY ATTRIBUTES FOR EQUIPMENT INSTALLATIONS

1. The Foundations should be based on achieving the most producible structural designs while meeting the requirements of the specifications. Since foundation design normally takes place after the functional arrangement of the equipment has been integrated into the ship design with supporting ships systems, there may be only limited geometrical flexibility remaining to achieve producible foundation designs. However, some accommodation by systems or equipment arrangements may be possible and should be pursued in order to achieve optimum producible foundations.

2. Develop designs which require a minimum number of operations per piece.

3. Make foundations rectilinear in configuration.

4. Foundation headers on opposite sides of bulkhead or deck should be avoided where possible. Production scheduling usually causes headers to be added after the basic structure is finished.

5. Provide sufficient access to facilitate installation and welding.

6. Lift foundation off structure

   - Reduces weld length/volume
   - Simplifies fitting in way of distorted deck and bulkhead plating
   - Reduces the possibility of "locked-in" stresses, and in some cases reduces hard spots
   - Flexible foundations decouple the equipment from the ship reducing the shock load on the equipment

7. Simplify foundation designs/improve fitting

   - Reduce manufacturing aids/lofting effort
   - Reduce number of pieces required
   - Substitute studs for welded plate foundations
   - Establish quality standards that are consistent with product functions
   - Eliminate unnecessary bolt chocks

8. The minimum use of under-deck and far side headers; the benefit:

   - Results in significant weld and weight reduction

- Eliminates/reduces lofting of headers and fitting problems associated with full depth headers
- Eliminates pre-outfitting and planning to install headers with sub-assemblies

9. Develop simple attachments, and mechanical fastening techniques.

10. Land foundation structures on soft plating, with minimum or no back-up structures provided vibration criteria are met.

11. By emphasizing producible frame and truss type equipment installations and installation configurations of minimum scantling thickness; the benefit:

    - Reduce weld size/passes
    - Elimination/reduction of prepared edges

12. Integrate Equipment installations with hull construction. The methods used to achieve this should be intelligently implemented so that the performance and maintenance of the supported equipment is not compromised with.

13. Simplify hull equipment items

    - Redesign top and bottom connections on bins, racks, storage cabinets and furniture support items

14. By the minimum use of bolt chocks and brackets, having the benefit of:

    - Minimizing cutting, handling, fitting, and welding small pieces

15. By the use of stud welding to the maximum extent possible including a unique approach using mounting plates installed with studs.

16. By utilizing "method mounting" standard installation techniques for lightweight equipment; the benefit:

    - Significantly reduces engineering analysis and construction time

FABRICATION AND INSTALLATION ATTRIBUTES

1. In general shapes, especially angle bar, produce the least expensive construction.

2. In some cases combining flanged plates and shapes may be less expensive.

3. In high weight equipment foundations weldments are approx. 60% more expensive than shapes. Further, in case of light weight foundations weldments are approx. 43% more expensive than shapes.

4. Weldments and flanged plate construction tend to be 7% to 10% heavier than shape construction.

5. Do not use a flanged plate to replace a standard shape. Consider flanged plates to replace weldments. Weldments may be used where shapes and/or flanged plates are impracticable.

6. Use simple attachments and mechanical fastening techniques, where applicable.

7. Replace welded support fabricated from pipe with a double ended shot stud, fabrication and weld of length of pipe is eliminated. Electrician is enabled to install foundation, since a shot stud is used rather than a welded foundation, pipe fitting trade is eliminated from process, fitting and welding trades are eliminated from installation process. Stud welding saves fitting and welding time.

8. Replaced angle and F.B. foundation with 4 threaded shoulder studs. Fabrication, fitting and welding of foundation are eliminated. Electricians can install foundation, eliminating the requirement for several trades to complete each foundation. Templating time when studs are shot is offset by templating and drilling time at time of equipment installation. Blast, paint, and insulation in way of studs is facilitated.

COST SAVING AND LABOR REDUCTION ATTRIBUTES

- Develop standard foundations for a variety of equipment
- Reduce welding
- Reduce material
- Reduced fabrication / fit-up
- Reduce installation time
- Develop simplified attachment techniques:
  - ✓ Reduces time for installation of foundations
  - ✓ Paves the way to install equipment and systems with their foundations
  - ✓ Reduces sub-assembly construction time on critical path
- Lighter weight deck backup pads are used which are easier to fabricate and install. Coping of angle in way of pad is eliminated.
- Lighter weld is used, decreasing weld time
- Snipe size is reduced, allowing a single continuous weld on each side of the chock to be used. Weld wrap around the chock at each side of the snipe opening is eliminated.
- Delete backup pads, save fabrication, fit up and weld time.
- Delete angle stiffening chocks, save fabrication, fit up, and weld time.
- Lifting angle off of deck or bulkhead
  - ✓ Deleted cope and pad at ends of angle, saving pad fabrication and installation, saving coping of angle.
  - ✓ Eliminate welding of angle to deck or bulkhead. Raised angle allows for complete painting without requiring complete seal welding. Fit up to irregular surface is simplified since only the chocks need be trimmed at installation.
- Relocate chock from bosom of angle to heel
  - ✓ Eliminates trimming to fit between flange and deck or bulkhead plate
  - ✓ Decreases welding by 1/3
- Delete chock, reduces material and fabrication, installation and weld time
- Deleted angle header, eliminates fabrication of header, fit and weld
- Extend chock past flange of angle, eliminate snipe on backside of chock
- Reduce thickness of pad or chock, reduces fabrication time, reduces weld required
- Replace flat bar attachment with chocks.

DEVELOP DESIGN ATTRIBUTES FOR DISTRIBUTIVE SYSTEM INSTALLATIONS

Under this task we have identified key design attributes which will reduce cost and cycle time. The design attributes and criteria for system installations were evaluated to address the Design for Manufacturing and Assembly (DFMA) concept. These attributes were further evaluated from actual manufacturing and installation aspects, where shipyard savings are significant. Information from NASCCO, Avondale, St. John Shipbuilding, KHI, and IHI standards were used to establish some of the cost saving attributes. Standard system installation techniques and methods were incorporated to establish these attributes. Vendor furnished information from TRW, RT&D, SAMTAN and Progressive Fastening Inc. providing standard methods of installation using COTS products were also identified and incorporated. Design methodologies to address these attributes for cost reduction and enhanced producibility were also devised, which will be later incorporated into the standards.

The design attributes for cost reduction, easy fabrication and installation are categorized into General Attributes and Individual Attributes. The General Attributes describe the features which potentially can be incorporated in to the installations for various types of system runs. The Individual Attributes demonstrate cost-saving and producibility features specific to that installation type.

GENERAL ATTRIBUTES

ATTRIBUTES	DESCRIPTION OF SAVINGS AND PRODUCIBILITY
AUTOMATED HANGER SELECTION	DEVELOPING A COMPUTERIZED SYSTEM (DFMA) THAT COULD PROVIDE A HANGER SELECTION GIVEN A MINIMUM NUMBER OF VARIABLE INPUTS (CABLE WEIGHT, SPACING, ETC.) WOULD BE VERY COST EFFECTIVE IN THE LONG RUN.
MINIMIZE WELDING	IN ALL CASES, THE MINIMUM REQUIRED WELD LENGTH AND THICKNESS SHOULD BE USED. THIS PRODUCIBILITY MEASURE COULD SAVE LABOR COST IF SIGNIFICANT NUMBERS OF HANGERS ARE INSTALLED.
SHOP WELDING	WHEREVER POSSIBLE WELDING SHOULD BE DONE IN THE SHOP RATHER THAN ON THE SHIP AS SHOP WELDING IS LESS LABOR INTENSIVE AND THEREFORE COST EFFECTIVE.
SHOP ASSEMBLY	AS MUCH HANGER ASSEMBLY AS POSSIBLE SHOULD TAKE PLACE IN THE SHOP TO SAVE LABOR ON THE SHIP.
METHOD MOUNTS	METHOD MOUNTS (STUDS, SPOOLS, AND FASTENERS) CAN BE CHEAPER AND LESS LABOR INTENSIVE THAN WELDED ANGLES.
HANGER DESIGN IMPROVEMENTS	AN AUTOMATED MACHINE CAPABLE OF BENDING SHAPES INTO THE PROPER HANGER CONFIGURATION MAY PROVE TO SAVE COSTS BY REDUCING CUTTING AND WELDING OF HANGERS.
ADJUSTABLE LENGTH HANGERS	PROVIDING AN ADJUSTABLE LENGTH FEATURE WOULD ALLOW MANY TYPES OF HANGERS TO BE STANDARDIZED AND MASS PRODUCED OR PURCHASED CHEAPLY, AS ONE HANGER COULD BE USED IN MANY SITUATIONS. A HANGER CAPABLE OF ATHWARTSHIP ADJUSTMENT AS WELL WOULD BE EVEN BETTER. THESE ADJUSTMENT FEATURE ELIMINATES THE NEED FOR TRIMMING OF LEGS. A SINGLE FILLET WELD WOULD BE THE ONLY LABOR NECESSARY.
VERSATILE DOWN-COMER DESIGN	DOWN-COMERS WHICH CAN SUPPORT SYSTEM RUNS OF ORTHOGONAL DIRECTIONS HELP MINIMIZE THE NUMBER OF HANGERS. PROGRESSIVE FASTENING DOWN-COMERS OFFER THIS.
ADJUSTABLE PIPE SLEEVE	SYSTEM RUN SUPPORTS AND STOOLS HAVING AN ADJUSTABLE PIPE.
STAND-OFF / LEGS	SLEEVE AS PART OF THEIR LEGS OR STANDS-OFF WILL ELIMINATE FIT-UP AND CUT TO SUIT PROBLEMS AND ALSO EASE THE PAINTING.
BRACE DESIGN	BRACE DESIGN SHOULD BE SUCH THAT THEY CAN BE MECHANICALLY FASTENED AT BOTH ENDS, WITH MINIMUM OR NO CUTTING, FIT-UP AND WELDING. RT&D BRACE DESIGN OFFERS THIS.
ALTERNATIVE BRACE DESIGN	BRACES CAN BE MADE UP OF PIPES OF STANDARD LENGTH AND SIZE, WITH THREADED

ATTRIBUTES	DESCRIPTION OF SAVINGS AND PRODUCIBILITY
	ENDS WITH LOCK-NUTS AND HAVE TURN-BUCKLE CONNECTIONS AT BOTH ENDS. THIS WILL ALLOW THE SAME STANDARD BRACE SIZE TO BE USED AT VARIOUS LENGTHS AND ORIENTATIONS.
LAP WELDS	WHERE POSSIBLE, USE A LAP WELD IN LIEU OF A SHAPED WELD. THIS CREATES AN EASIER FABRICATION PROCESS AND ALLOWS FOR ADJUSTMENT.
RACKS FOR MULTIPLE SYSTEMS	THIS ALLOWS RACKS TO BE BUILT IN PARALLEL WITH THE BLOCK BEING OUTFITTED, THUS REDUCING OVERALL CYCLE TIME.
USE SHIP STRUCTURE TO LOCATE RACKS	USE EXISTING WEBS AND BEAMS AS HANGER LOCATIONS. THIS MINIMIZES BOTH LAYOUT AND INSTALLATION TIME. IN ADDITION, MULTIPLE HANGERS CAN BE USED AS TEMPLATES FOR LOCATIONS OF WELD STUDS.
SYSTEM RUN DIRECTION	SYSTEMS SHOULD BE RUN FORE AND AFT OR ATHWARTSHIP TO UTILIZE SHIP STRUCTURE AND ENABLE HANGER INSTALLATION TO BE ROUTINE AND THEREBY COST EFFECTIVE.
VENDOR PURCHASE	WHEREVER PRACTICAL, PURCHASE HANGERS (DOWNCOMERS, CROSSTIERS, ETC.) FROM AN OUTSIDE VENDOR AND ASSEMBLE IN HOUSE. THIS SAVES FABRICATION TIME.
BANDING CABLES	GROUPS OF CABLES HEADING THE SAME WAY SHOULD BE BANDED TOGETHER TO SAVE LAYOUT TIME.
UNDESIRED LOCATIONS	CABLES SHALL BE INSTALLED TO AVOID UNDESIRED LOCATIONS SUCH AS: ▪ EXCESSIVE MOISTURE AREAS ▪ NEAR MAGNETIC COMPASS ▪ IN LOCATIONS EXPOSING THE CABLE TO MECHANICAL DAMAGE ▪ IN LOCATIONS CREATING AN INTERFERENCE WITH MACHINERY REMOVAL ▪ IN AREAS THAT ARE HAZARDOUS OWING TO A FLAMMABLE OR EXPLOSIVE ATMOSPHERE IN ACCESSIBLE SPACES
EXCESSIVE HEAT AREAS	THREADED PARTS EXPOSED TO THE WEATHER, SEA WATER, OR MOISTURE SHALL BE COATED WITH AN ANTI-SEIZE COMPOUND.

METHOD 1

U-BOLT ASSEMBLY W/ STAND-OFF OR STOOL

- USE LAP WELD THAN FIT-UP TO ATTACH LEGS TO THE SUPPORT PLATE/ANGLE
- USE PIPE W/ SLEEVE INSTEAD OF ANGLE FOR LEGS, GIVES HEIGHT ADJUSTMENT FLEXIBILITY AND EASE OF PAINTING

METHOD 2

CLAMP HANGERS

- REPLACE WELD ATTACHMENT AT SHIP STRUCTURE WITH STUD MOUNTING
- USE U-BOLTS IN PLACE OF FABRICATED CLAMPS WHERE POSSIBLE
- USE ADJUSTABLE BRACING WITH MECHANICAL FASTENERS THAN WELDED FIXED LENGTH BRACE

CLAMP AND CHANNEL HANGERS

- USE STANDARD CHANNEL SIZES
- USE ONE LONG CHANNEL TO ACCOMMODATE MULTIPLE PIPES, THAN USE SHORT PIECES FOR EACH PIPE.

METHOD 3

FULL CAP /BAND HANGERS

- USE U-BOLTS IN PLACE OF FULL CAP WHERE POSSIBLE

FULL CAP /BAND HANGERS W/ STAND-OFF OR STOOL

- SEE METHOD 1 ATTRIBUTES

METHOD 4

SINGLE LEG “L” BAND HANGER

- USE COMMERCIALLY AVAILABLE L-LEG THAN FABRICATE

METHOD 5

RTD STUD HANGERS

- REDUCE THE NUMBER OF PIECES FOR THE BRACE
- FASTEN THE BRACE DIRECTLY TO THE DOWN-COMER W/O ANY CLAMP

NELSON TYPE HANGERS

- REPLACE TWIST KEY WITH TIE ROD

METHOD 6

RESILIENT HANGERS

- REDUCE THE NUMBER OF PIECES

- DEVICE AN ALTERNATIVE TO THE DOG-NIPPLE ASSEMBLY

METHOD 7

RUBBER BLOCK HANGERS

- Replace Down-comer Angle with Pipe, where possible

ELECTRICAL SYSTEMS

INDIVIDUAL ATTRIBUTES

METHOD 1

NELSON STUD CABLE SUPPORT

- SEVERAL STANDARD STUD LENGTHS WITH THE SAME DIAMETER
- SEPARATE CABLE STRAP WHICH FITS ALL STUD LENGTHS
- USE THREADING TO FINE TUNE VERTICAL POSITION

CH TYPE CABLEWAY

- STANDARD CHANNEL SECTION
- FULL SPAN OF CHANNEL MAY NOT BE NECESSARY
- ATTACH FLATBAR TO WEB (NOT FLANGE) WITH LAP WELD TO ALLOW HEIGHT ADJUSTMENT

L TYPE CABLEWAY

- STANDARD FITTING PIECE SIZES
- USE LAP WELD TO ADJUST HEIGHT
- STANDARD ANGLE SIZES
- CONTINUOUS ANGLE RUNS MAY NOT BE NECESSARY

HANGER TYPE CABLEWAY SF, SH

- STANDARD HANGER SIZE
- STUD WELD IF POSSIBLE

METHOD 2

TYPE A/C T-GRID CEILINGS

- ASSEMBLE FRAMEWORKS IN SHOP OR PURCHASE
- ATTACH NELSON CLAMP IN SHOP WITH STUD WELD
- ASSEMBLY SHOULD BE HEIGHT ADJUSTABLE (THREADING ON CLAMP)

METHOD 3

HONEYCOMB BULKHEAD HANGER

- USE WELD INSTEAD OF RIVET

- STANDARD BRACKET SIZE

METHOD 4

SECURING LOCAL CABLES ON SHEATHING

- SINGLE CABLE CLAMP SIZE

METHOD 5

TUBULAR HANGERS

- ASSEMBLE STUD AND T-BAR IN SHOP
- STANDARD T-BAR SECTION
- STANDARD STUD DIAMETER WITH VARIABLE LENGTHS FOR HEIGHT ADJUSTMENT

METHOD 6

SUPPORTING T-BAR HANGERS ON BULKHEADS USING CHANNEL

- ATTACH T-BARS TO CHANNEL IN SHOP
- STANDARD CHANNEL SECTION
- USE LAP WELDS

METHOD 7

SUPPORTING CABLES RUNNING ON CEILING FURRING

- STANDARD JAMMING BARS TO FIT DIFFERENT FURRING SIZES
- SEEK ALTERNATE ATTACHMENT METHOD AS JAMMING BAR WELD LOOKS LABOR INTENSIVE. PERHAPS WELDING THE STUD DIRECTLY TO THE FURRING OR PLACING THE JAMMING BAR ON TOP OF THE FURRING WOULD BE EASIER.
- USE THREADING AS HEIGHT ADJUSTMENT
- USE STANDARD T-BAR SECTION

METHOD 8

CABLES MOUNTED ON PIPE SUPPORTS

- STANDARD WIDTH STRAPS

METHOD 9

CROSSTIERS ON CHANNEL DOWNCOMER

- BUY STANDARD CHANNELS AND CROSSTIERS TO ASSEMBLE IN SHOP
- ADEQUATE HOLES FOR HEIGHT ADJUSTMENT
- CONSIDER ADAPTER BRACKET FOR EASE OF ATTACHMENT AND REMOVAL
- STANDARD WIDTH STRAPS
- USE SHIP STRUCTURE TO LOCATE AND THEN USE LAP WELD

METHOD 10

SUPPORTING VERTICAL TIERS OF CABLE INDEPENDENT OF SHIPS STRUCTURE WITH METHOD 9 HANGERS

- STANDARD CHANNEL SECTIONS FOR VERTICAL PIECE
- ASSEMBLE CHANNEL DOWNCOMERS AND CROSSTIERS IN SHOP
- USE STANDARD ASSEMBLY PADS

METHOD 11

TRAPEZE TYPE CROSS-TIERS AND CABLE TROUGHS

- BUY STANDARD CHANNELS AND CROSS-TIERS TO ASSEMBLE IN SHOP
- ADEQUATE HOLES FOR HEIGHT ADJUSTMENT
- CONSIDER ADAPTER BRACKET FOR EASE OF ATTACHMENT AND REMOVAL
- USE STANDARD WIDTH CABLE STRAPS
- USE SHIP STRUCTURE TO LOCATE HANGERS AND USE LAP WELDS

TRAPEZE WITH PIPE

- STANDARD FITTING PIECES, LAP WELD TO ADJUST HEIGHT
- ATTACH TO WEB RATHER THAN FLANGE
- STANDARD PIPE DIAMETERS
- STANDARD ANGLE SIZES (SECTION AND LENGTH)
- STANDARD WIDTH CABLE STRAPS
- USE SHIP STRUCTURE TO LOCATE HANGERS AND USE LAP WELDS

METHOD 12

SUPPORTING CABLES IN DECKS AND BULKHEADS WHERE WIREWAY SPACE IS LIMITED

- STANDARD CHANNEL SECTION
- TACK WELD INSTEAD OF FULL WELD
- USE FLATBAR TO LIFTOFF TO ADJUST HEIGHT
- STANDARD WIDTH CABLE STRAPS

METHOD 13

SUPPORTING CABLES WITH PORTABLE FLATBAR U-BRACKET

- STANDARD FLATBAR SIDE BRACKETS
- STANDARD WIDTH CABLE STRAPS
- SINGLE BOLT SIZE
- USE HOLE POSITION TO GOVERN HEIGHT ADJUSTMENT

VENTILATION / DUCTING SYSTEMS

INDIVIDUAL PARAMETERS

METHOD 1

ANGLE / FLAT BAR DOWN-COMER HANGERS & ANGLE / FLAT BAR DOWN-COMER W/ CLAMPS HANGERS

- FOR DOWN-COMERS USE STUD MOUNTING IN PLACE OF WELDING TO THE SHIP STRUCTURE
- USE DOWN-COMERS WITH ADJUSTABLE LENGTH FEATURE – SEE RT&D TYPE DOWN-COMERS

METHOD 2

RTD DUCT HANGERS

- SEE ATTRIBUTES FOR RTD STUD HANGERS IN PIPING SECTION

METHOD 3

RESILIENT DUCT HANGERS

- USE COMMERCIALLY AVAILABLE CLAMPS
- USE FLEXIBLE LENGTH DOWN-COMERS

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO.4 — BOUND THE PROBLEM

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TABLE OF CONTENTS

LIST OF FIGURES

4 BOUND THE PROBLEM

BOUND EQUIPMENT INSTALLATION PARAMETERS

This section describes and outlines the ranges of various parameters considered for Equipment Installations. The various methods, techniques and concepts of equipment installations to be later incorporated into the standards development are also discussed here. The equipment foundation and installation parameters were evaluated and a range for the variables was established which will be used to analyze and develop the standards. By bounding the parameters we have obtained min/max constraints and variations of the physical geometry, arrangements, installation parameters, ship structure interface scenarios, and effects of equipment installations' physical locations.

The equipment installations can be categorized into various standard foundation types. Vibtech has established 27 different standard foundation types, which will encompass almost all of the equipment installation types for shipboard application (see Figure 4-1). Of these standard foundation types, 3 are most frequent and are therefore adopted for the initial identification and bounding of the variables. These 3 foundation types are Grillage, Frame, and Truss, (see Figure 4-2, Figure 4-3, and Figure 4-4). Other than the standard foundation types, 18 different method mount types were also looked into to in order to bound the parameters. The most important issue addressed in this section is the development of improved designs that simplify the manufacture and installation of foundations and attachments, (see Figure 4-5, Figure 4-6, and Figure 4-7), that may be used to rapidly install or attach foundations to the ship's structure. While foundation standards are important in and of themselves, improved rapid attachment methods (see Figure 4-5, Figure 4-6, and Figure 4-7), will accelerate outfitting of foundations for equipment and will reduce overall construction time and hence the overall construction schedule.

General design parameters that affect the design such as loading, vibration, noise, fatigue, allowable stress, etc. were reviewed and a preliminary estimation of the effect of these parameters on design was done. Some of these estimations are elaborated in the report of Section 2.A.

The Grillage type foundations have been traditionally welded completely to the mounting surface; i.e., deck or bulkhead, (see Figure 4-2). Grillages can be designed to be lifted off the mounting plate, (see Figure 4-5), using a variety of attachment details. In that case they are similar to method mounts. Grillages completely welded on to the mounting plate may have backup structures like far-side headers, chocks, and brackets to increase its strength and rigidity. However, if the vibration and fatigue criteria are met, grillages may be directly attached to the soft mounting plate with minimum or no back-up structures.

The parameters for Grillages include:

- Mounting Plate (deck or bulkhead) Thickness – 3/16 to 3/4 inches
- Scantling Sizes – 2"x2"x3/16" to 4"x4"x1/2" Angles

The Frame type foundations have their legs completely welded to the ship structure, with adequate tie-up pieces (see Figure 4-3).

The parameters for Frame type foundations include:

- Mounting Angle Span Length – 10 to 50 inches
- Scantling Sizes – 2"x2"x3/16" to 4"x4"x1/2" Angles
- Frame Leg Length – 6 to 36 inches

The Truss type foundations are similar to the Frame type, except for the diagonal pieces bracing the legs to increase the lateral stiffness of the foundation (see Figure 4-4).

The parameters for Truss type foundations include:

- Mounting Angle Span Length – 10 to 50 inches
- Scantling Sizes – 2”x2”x3/16” to 4”x4”x1/2” Angles
- Truss Leg Length – 6 to 36 inches

The Method Mount Foundation types are basically variations of the Grillage type foundations lifted off the mounting plate (deck or bulkhead) and integrating the ship structure into its design for cost reduction (see Figure 4-5, Figure 4-6, and Figure 4-7). Some of the Method Mounts are designed for mounting multiple equipment on one integrated foundation.

The parameters for Method Mounts include:

- Mounting Angle Span Length – 10 to 50 inches
- Mounting Angle Overhang Length – 10 to 50 inches
- Mounting Plate Thickness – 3/16 to 3/4 inches
- Scantling Sizes – 2”x2”x3/16” to 4”x4”x1/2” Angles

The other 24 foundation types have some of their basic features similar to that of Grillage, Frame or Truss, along with some other attributes unique to them. These designs have been developed based on statistics of repeated use on a variety of ship types. The final standards incorporate all of these 27 foundation types as standard foundation types.

Apart from the foundation types made-up of steel sections, two other methods of equipment installations were also evaluated. They are Stud-mounted equipment (see Figure 4-6) and Spool-mounted equipment (see Figure 4-7). These two foundation types are the simplest ones, needing virtually no fabrication as they come in standard shapes and sizes, and are mostly used to mount light to medium weight equipment.

The parameters for Studs include:

- Mounting Plate Thickness – 3/16 to 3/4 inches
- Stud Sizes – 5/16” to 3/4”
- Stud Length – 1 to 12 inches

The parameters for Spools include:

- Mounting Plate Thickness – 3/16 to 3/4 inches
- Spool Sizes – 2.5” diameter to 4” diameter
- Spool Length – 3 to 12 inches
- Stud Sizes – 1/2” to 3/4”

The parameters of various equipment installation types and their respective min/max and ranges will be used as the starting point for the engineering analysis and standards development.

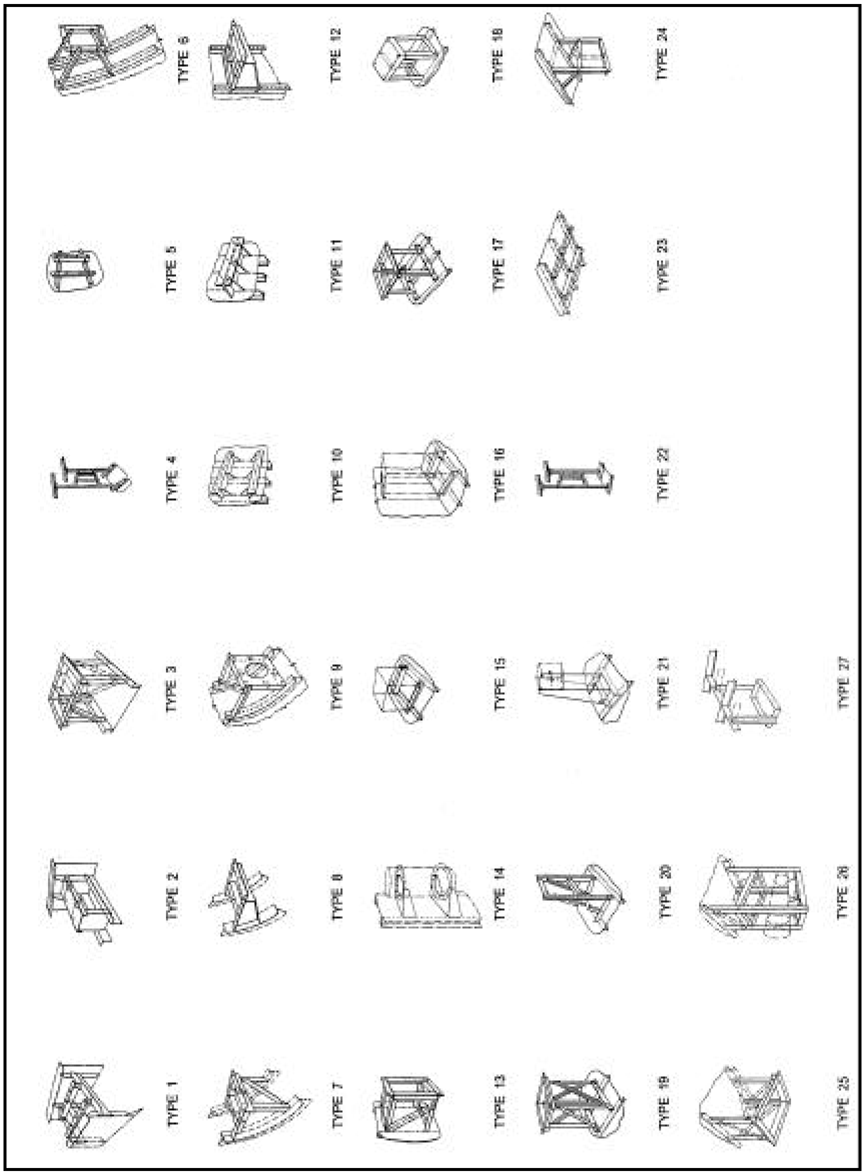


Figure 4-1 — Standard Foundation Types

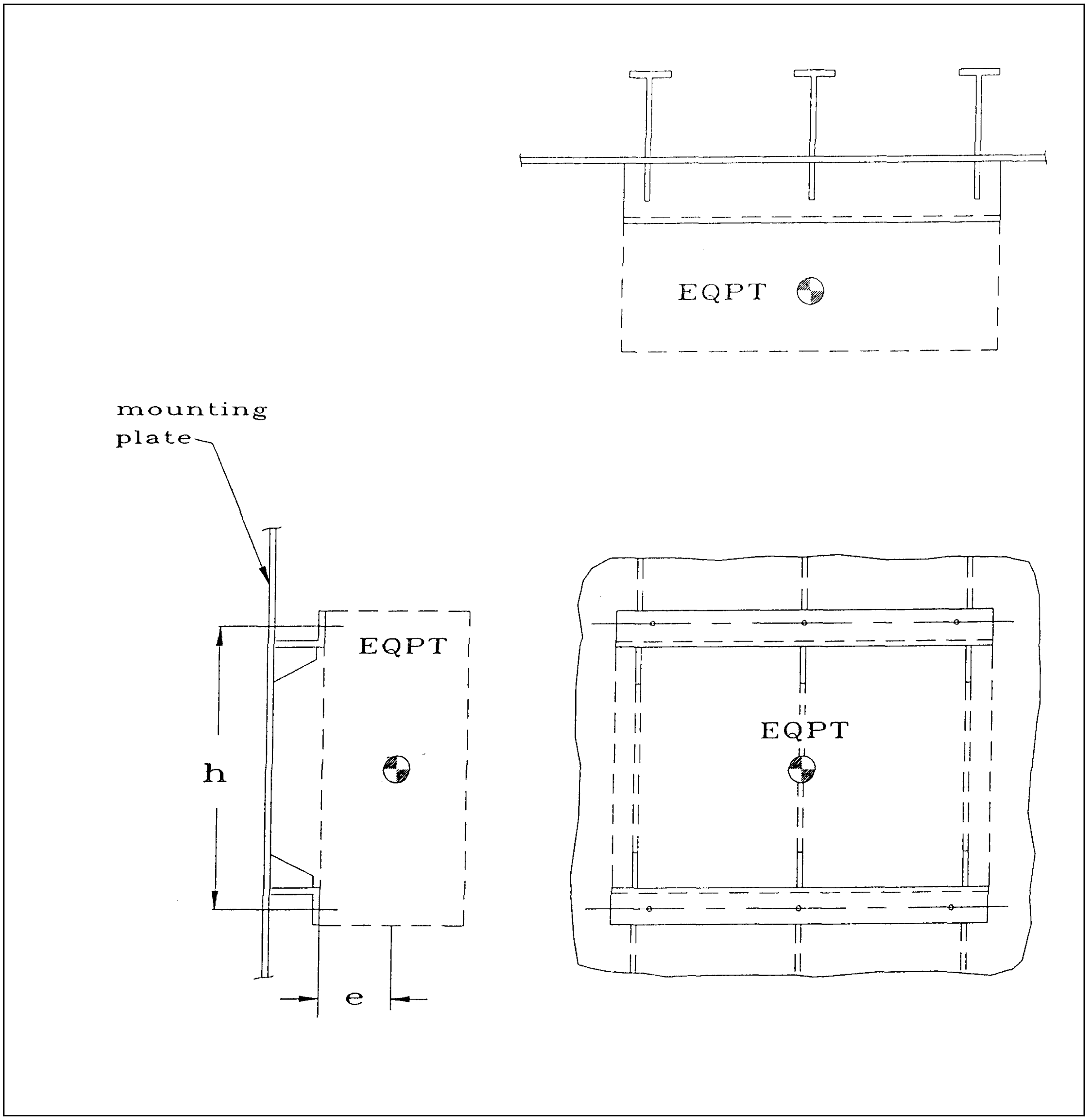


Figure 4-2 — Grillage

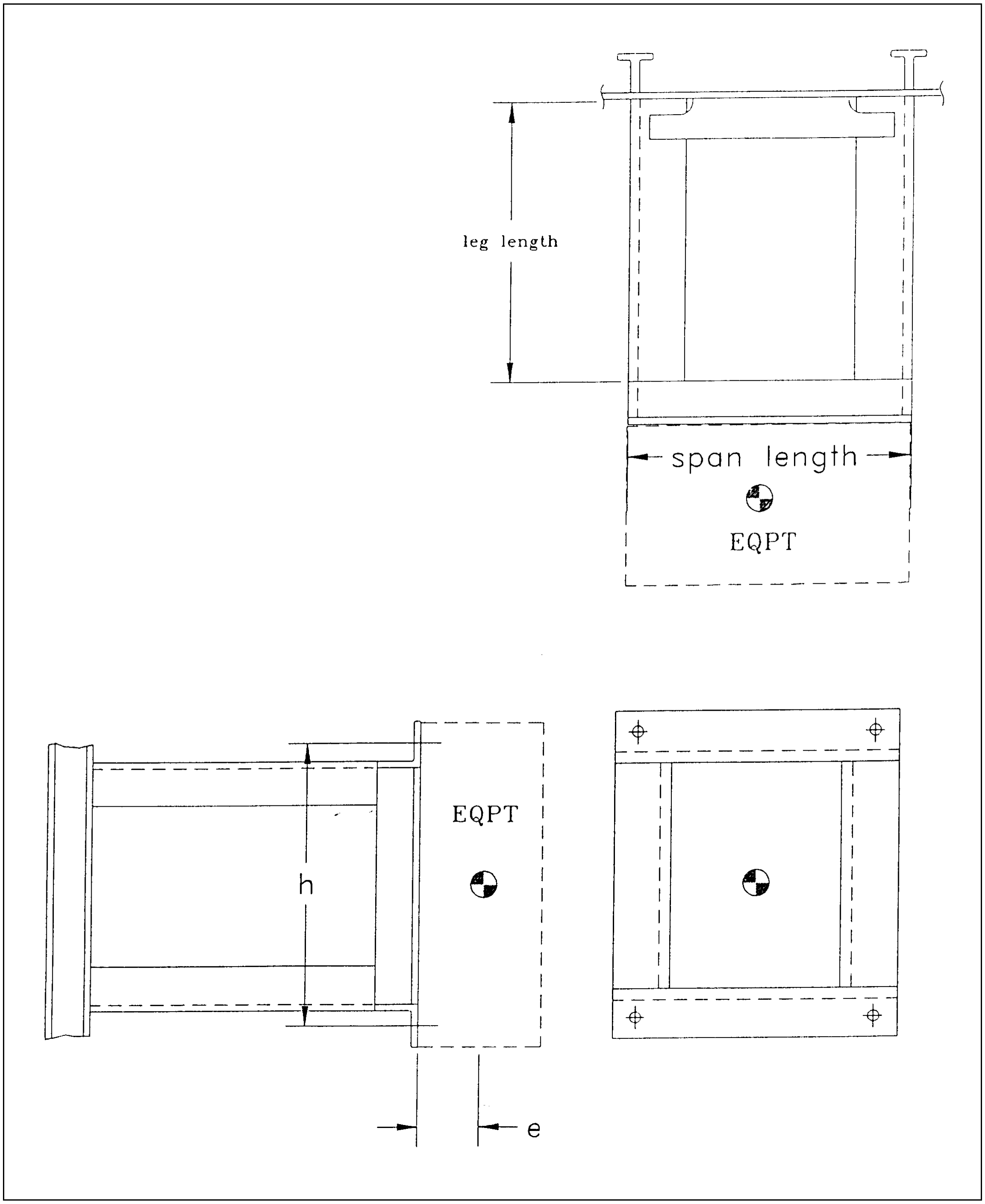


Figure 4-3 — Frame

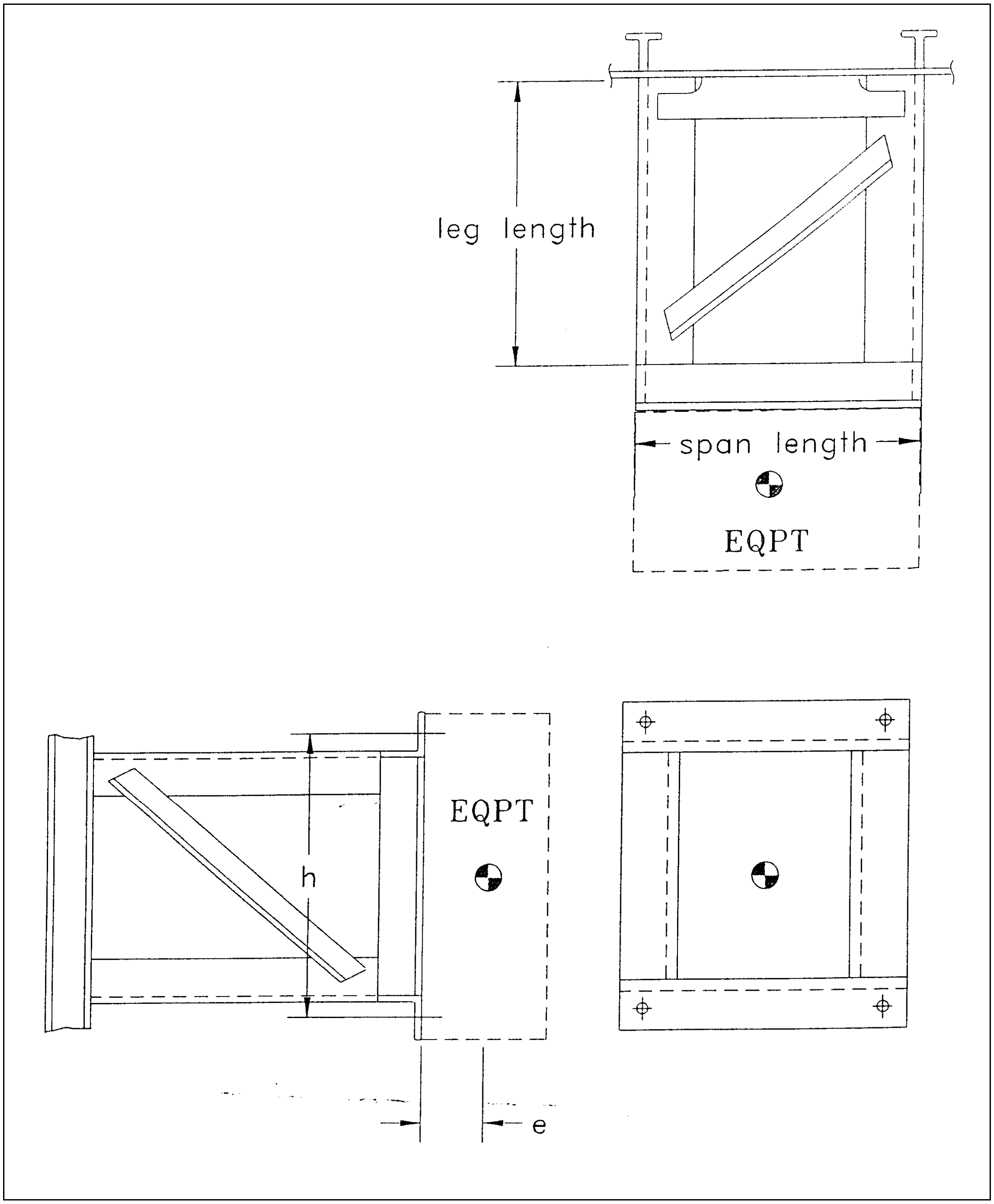


Figure 4-4 — Truss

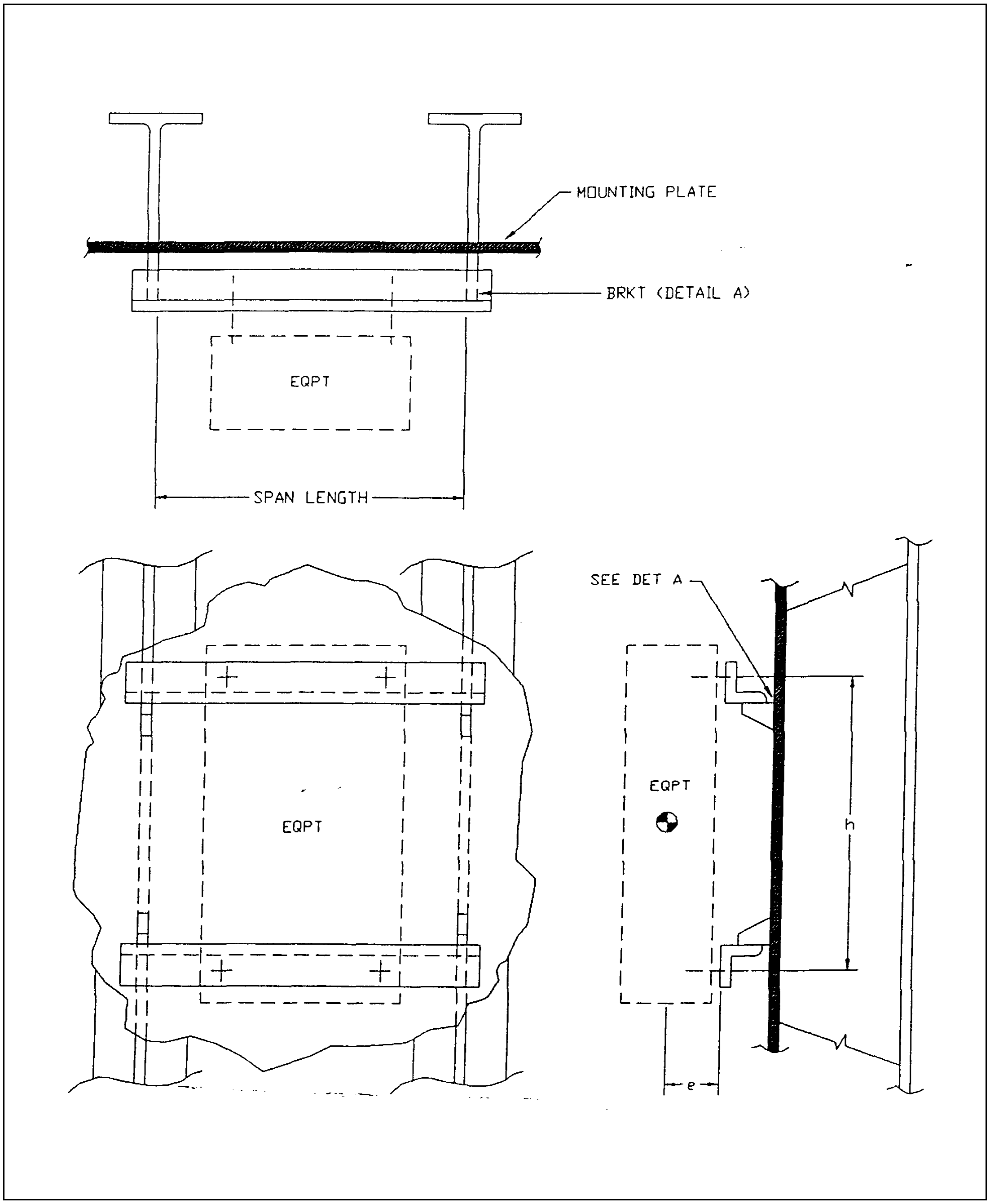


Figure 4-5 — Method Mount Illustration

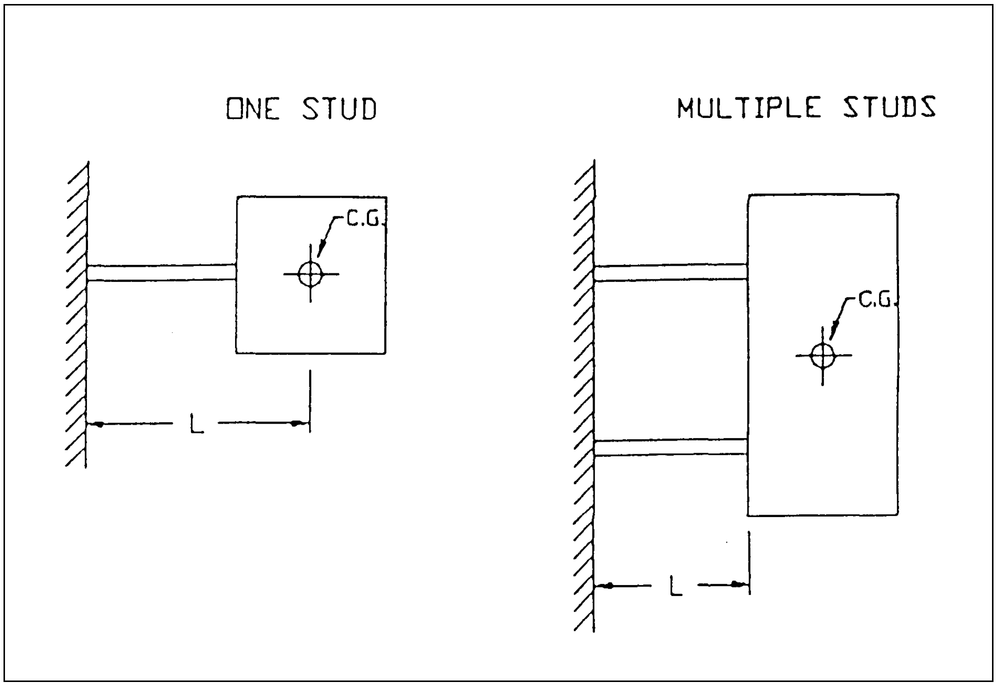


Figure 4-6 — Stud Mounted Equipment

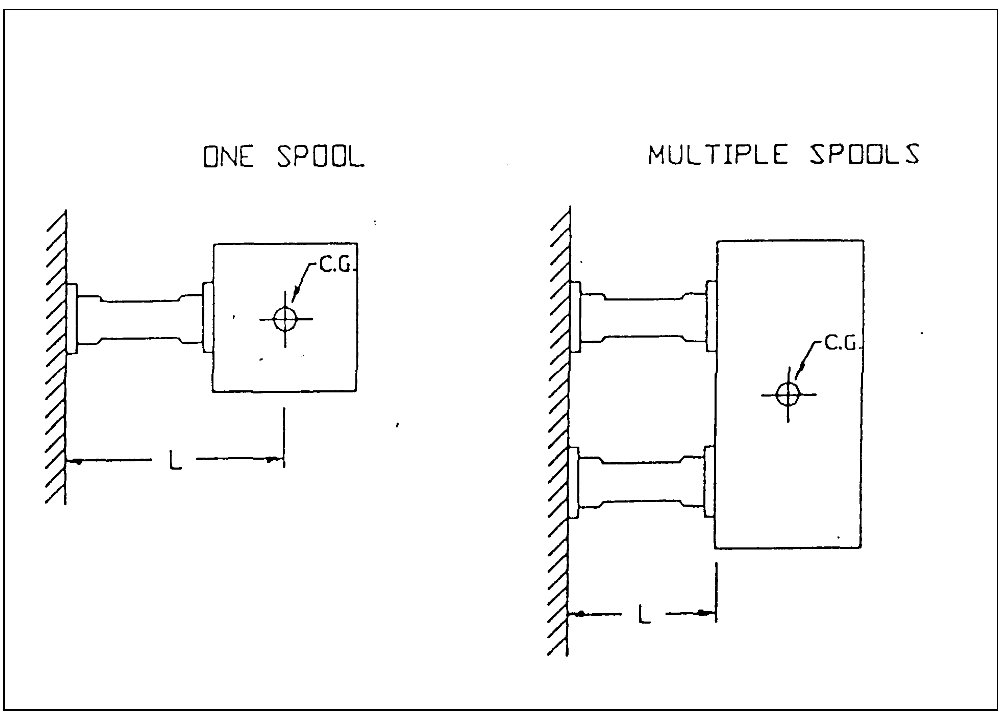


Figure 4-7 — Spool Mounted Equipment

BOUND DISTRIBUTIVE SYSTEM INSTALLATION PARAMETERS

This section report describes and outlines the ranges of various parameters considered for System Installations. The distributive system installation parameters were evaluated and a range for the variables was established which will be used to analyze and develop the standards. The parameters identified earlier were bound by establishing a min/max and increments of the various physical geometry, sizes, arrangements, installation constraints, installation attachments, fastening methods, ship structure interface scenarios, and effects of installations' physical location. The parameters were evaluated for certain representative group of installation types, rather than evaluating specifics of every type of installation. The installation types evaluated fall under three major ship-system categories, namely, Piping, Cable/Wireways, and Ventilation/Ducting. A fourth category was also established, not based on ship-system, but based on ship-structure interface. This category is installations on Joiner Bulkheads.

General parameters like loading, vibration, noise, fatigue, allowable stress, etc., were reviewed, and a preliminary estimation of these parameters was done. Some of these estimations are elaborated in the report of Section 2.B.

The materials for straps, saddles, U-bolts, and studs should be commercial quality carbon steel. The steel should be a weldable grade with a minimum tensile strength of 47 KSI. The material should be capable of being bent at room temperature through 90^{o} to an inside radius equal to the material thickness without cracking on the outside of the bend. Bands, Caps, and Buckles should be electroplated zinc carbon steel or stainless steel. Bolts and Nuts should be regular series hex electroplated zinc type as per ASTM standards or shipyard specifications.

System Installations located in areas subject to corrosion, such as in bilge's, ballast tanks, and areas exposed to the weather, should be zinc-plated or blasted and coated with inorganic zinc or coated with the same material as that of the surrounding area.

Long system runs, such as on the weather deck or in longitudinal passageways which are affected by ship flexing or systems which have considerable thermal growth should consider certain design considerations Criteria to be onsiderated include clearance type hangers and/or have a rider bar or wear strip made of metal, rubber, neoprene or plastic material as deem appropriate attached to or running along the system to prevent chaffing or other damages to the system. In case of excessive thermal growth in the system, the hangers should have means to absorb and allow any thermal distortions and prevent the system for over-stressing.

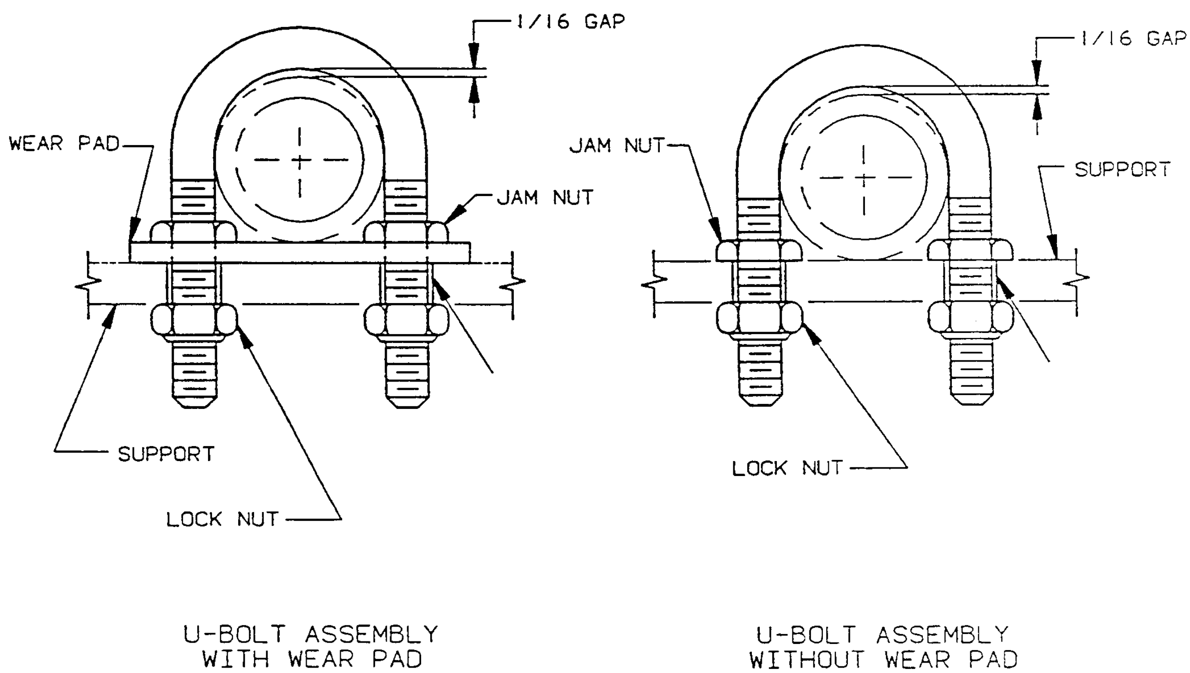
System layout and hanger spacing should be determined at the process modeling stage. The spacing should be governed by the weight of the system, accessories, and fittings, along with the associated fluid and also by the spacing between the ship-structure stiffeners. Special considerations should be given to areas of concentrated loads, such as risers, valves, groups of fittings, branch-off ducts, extra-length coils of cables, and wireways, etc.

PIPING SYSTEMS

INDIVIDUAL PARAMETERS

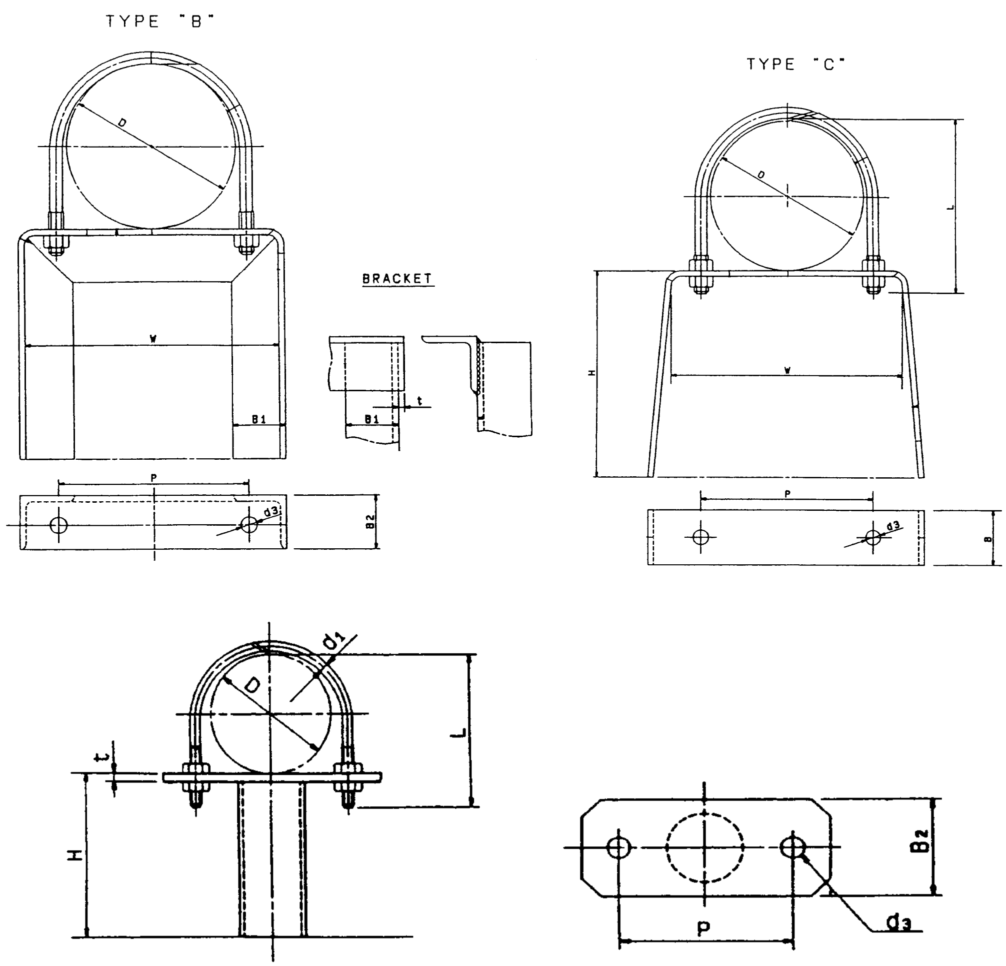
METHOD 1

U-BOLT ASSEMBLY HANGERS



U-BOLT ROD DIAMETER	0.25” – 2”
LENGTH OF ROD	5” – 100”
LENGTH OF THREADS	1.5” – 5.5”
INSIDE RADIUS OF U-BOLT	0.3125” – 18.0625”
WEAR PAD THICKNESS	0.25” – 1”
CLEARANCE FOR DISTORTION & THERMAL GROWTH	1/32” – 1/8”

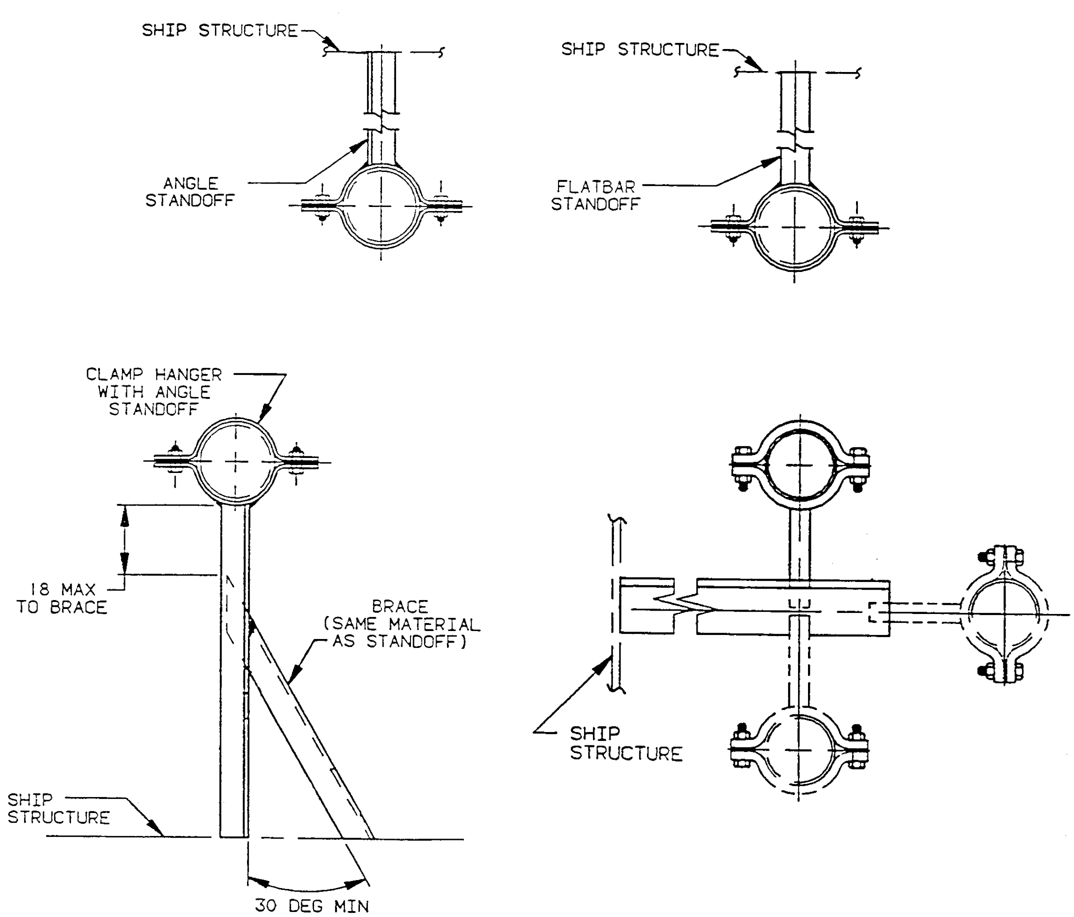
U - BOLT ASSEMBLY W/ STAND-OFF OR STOOL



SAME AS U-BOLT ASSEMBLY AND STOOL ANGLE BRACKET SIZES	1.5”×1.5”×0.1875” – 5”×3”×0.3125”
STOOL FLAT-BAR THICKNESS	1.5”×0.1875” – 4”×0.3125”
STOOL WIDTH	3” – 30”
STOOL HEIGHT	6” – 18”
STAND-OFF PIPE SIZES	1” – 6” (SCH 40 – 80)
STAND-OFF PIPE LENGTH	3” – 12”
SUPPORT PLATE FLAT-BAR SIZES	2”×0.1875 – 4”×0.25”

METHOD 2

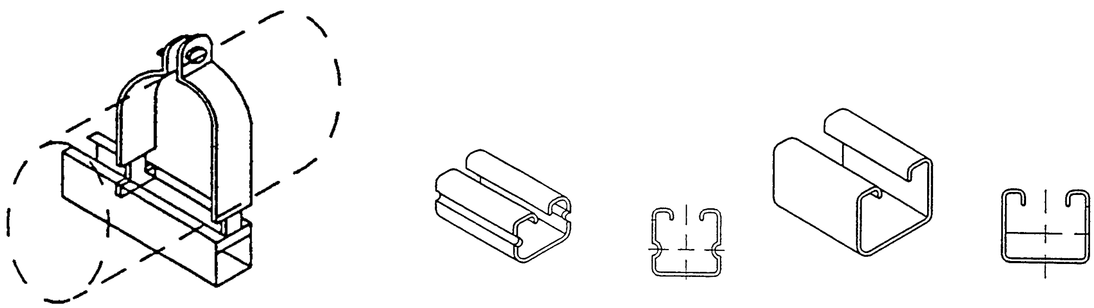
CLAMP HANGERS



CLAMP FLAT BAR SIZES	1”×0.25” – 4×0.75”
LENGTH OF CLAMP FAT BAR	4” – 48”
CLAMP BEND RADIUS	0.375” – 12.1875”
BOLT SIZE	0.375” – 1.375”
STAND-OFF / DOWN-COMER ANGLE SIZE	0.75”×0.75”×0.125” – 4”×4”×0.5”
STAND-OFF / DOWN-COMER FB SIZE	0.75”×0.1875” – 3”×0.5”
STAND-OFF / DOWN-COMER LENGTH	6” – 18”
INSULATION AND LINER/SHIELD CLEARANCES	0.75” – 2.5”

CLEARANCE FOR DISTORTION AND THERMAL GROWTH	1/32" – 1/8"

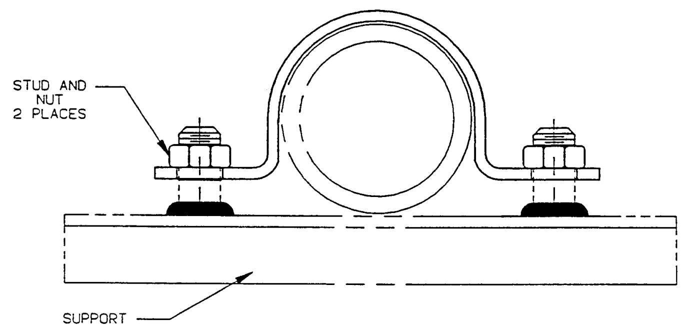
CLAMP AND CHANNEL HANGERS

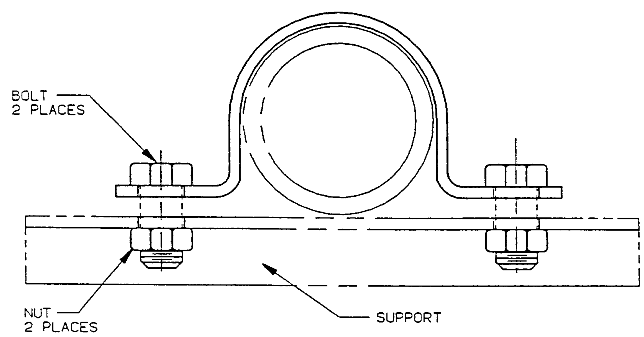


SAME AS CLAMP HANGERS AND CLAMP NECK WIDTH	0.25" – 1"
BOLT / SCREW SIZE	0.375" – 1"
NUMBER OF CLAMPS	1 – 6
CHANNEL (UNISTRUT) SIZES	C2"×0.75"×0.1875" – C4"×2"×0.375"
CHANNEL LENGTH	24" – 120"

METHOD 3

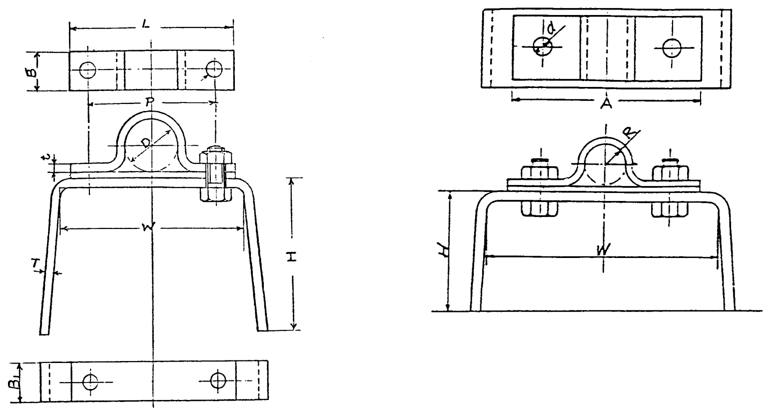
FULL CAP / BAND HANGERS





BAND FLAT BAR SIZES	1”×0.25” – 4×0.75”
BAND FLAT BAR OVERALL LENGTH	4” – 48”
BAND BEND RADIUS	0.375” – 12.1875”
BOLT / STUD SIZE	0.375” – 1.375”

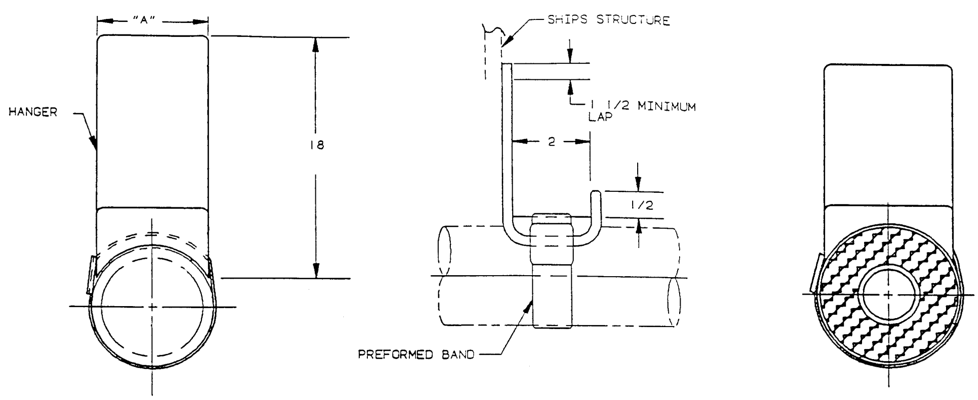
FULL CAP / BAND HANGERS W/ STAND-OFF OR STOOL



SAME AS FULL CAP / BAND HANGERS AND ANGLE BRACKET/FLAT-BAR STOOL – SAME AS U-BOLT ASSEMBLY STAND-OFF OR STOOL

METHOD 4

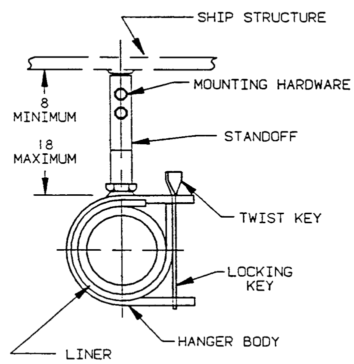
SINGLE LEG “L” BAND HANGER

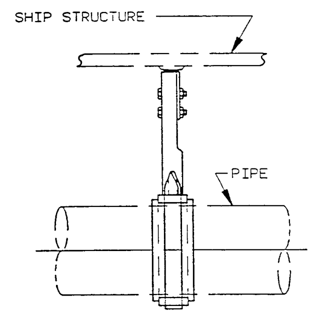


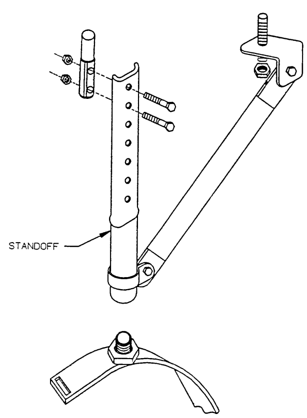
LEG FLAT BAR SIZES	1”×0.125 – 3”×0.25”
LEG LENGTH	6” – 18”
LEG CURVATURE INNER RADIUS TO SUIT CURVATURE OF PIPE SIZES	(0.25” – 6”)
PRE-FORMED BAND SIZES	0.5”×1/32” – 1.5”×1/16”
INSULATION AND LINER MATERIAL CLEARANCE	0.75” – 2.5”

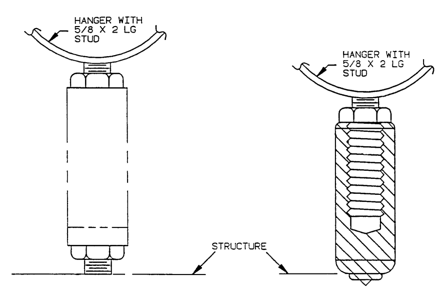
METHOD 5

RTD STUD HANGERS



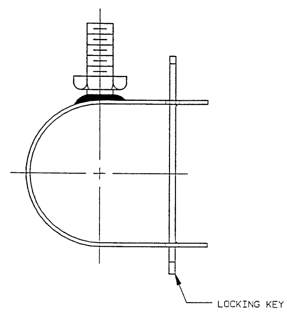


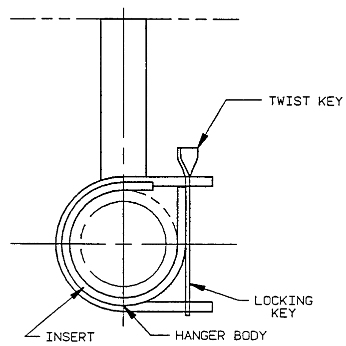


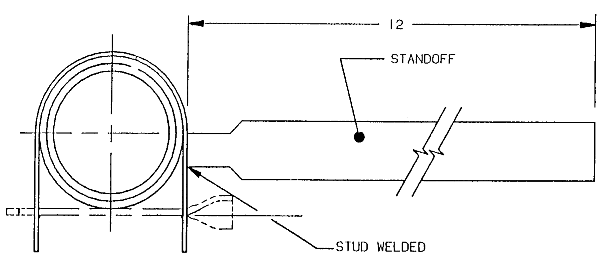


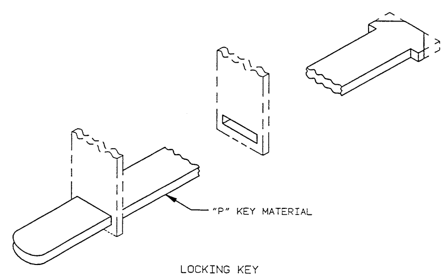
HANGER BODY FLAT BAR SIZES	1”×0.25” – 4×0.75”
STAND-OFF STEEL PIPE SIZES	1” – 4” (SCH 40 – 80)
STAND-OFF LENGTH	3” – 36”
LOCKING KEY FLAT BAR SIZES	0.5”×0.078” – 0.75”×0.125”
LOCKING KEY LENGTH	3” – 6”
BRACE LENGTH (FOR STAND-OFF ≥ 18”)	18” – 36”
BRACE PIPE SIZES	1” – 3” (SCH 40 – 80)
STAND-OFF TO SHIP STRUCTURE CONNECTING STUD SIZE	0.375” – 1.25”
BRACE TO SHIP STRUCTURE CONNECTING STUD SIZE	0.25” – 0.75”
BRACE TO STAND-OFF CONNECTING BOLT SIZE	0.25” – 0.75”

NELSON TYPE HANGERS





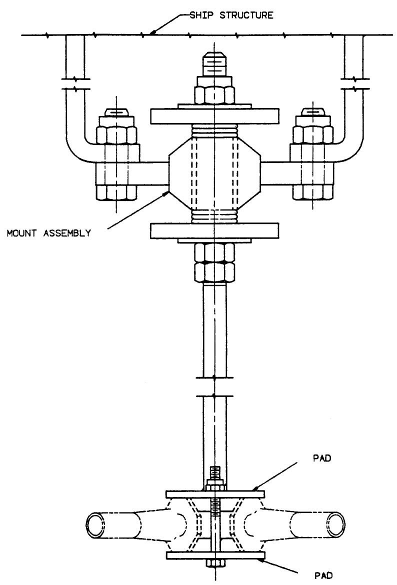


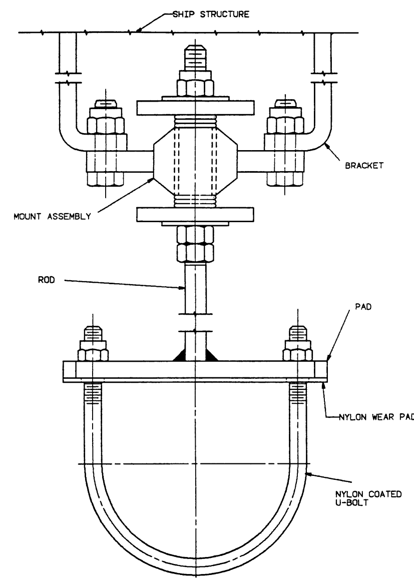


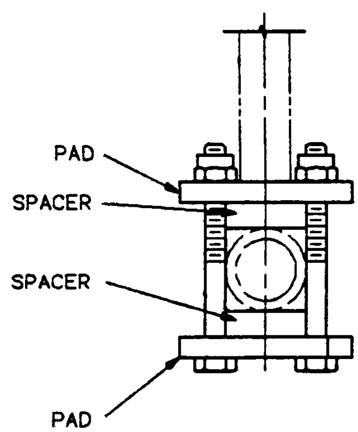
HANGER BODY FLAT BAR SIZES	SAME AS RTD TYPE
STAND-OFF/DOWN-COMER FLAT BAR SIZE	0.75”×0.1875” – 4”×0.5”
STAND-OFF/DOWN-COMER LENGTH	3” – 24”
LOCKING KEY FLAT BAR DIMENSIONS	SAME AS RTD TYPE

METHOD 6

RESILIENT HANGERS





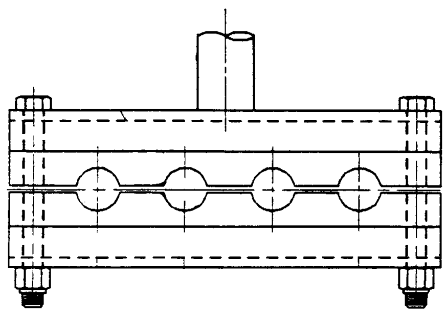


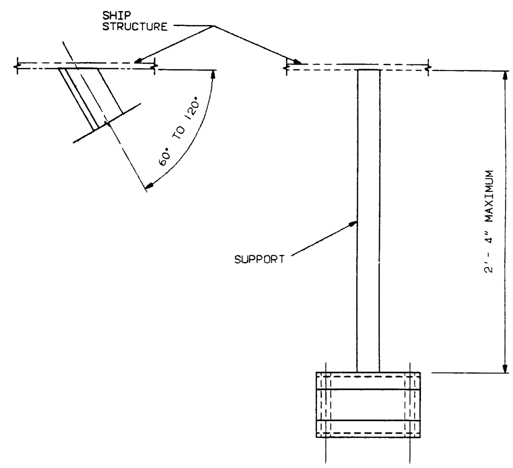
BRACKET FLAT BAR SIZES	1.5”×0.25” – 4”×0.5”
BRACKET LENGTH	6” – 18”
ROD DIAMETER	0.375” – 0.75”
ROD LENGTH	6” – 18”
MOUNTING PAD THICKNESS	0.375” – 0.625”

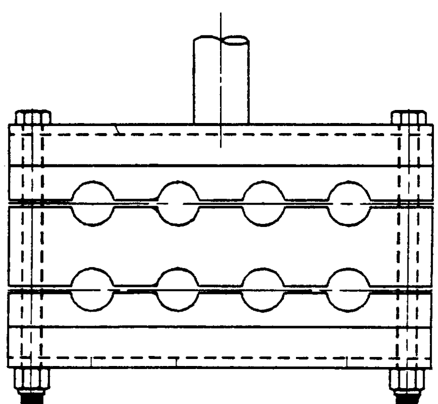
U-BOLT ROD DIAMETER	0.25" – 1"

METHOD 7

RUBBER BLOCK HANGERS



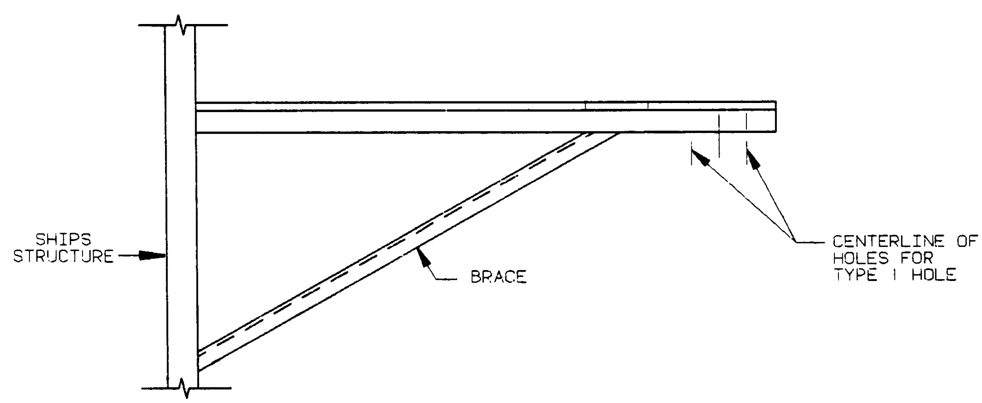




NO. OF TIERS OF PIPING	1 – 2
NO. OF PIPES PER TIER	2 – 4
SUPPORT DOWN-COMER ANGLE SIZES	1.5"×1.5"×0.125" – 3"×3"×0.3125"
SUPPORT DOWN-COMER LENGTH	4" – 18"
BOLT SIZES	0.25" – 0.5"

RUB. BLOCK RETAINER CHANNEL SIZES	C1.5”×0.75”×0.1875” – C3”×1.5”×0.3125”
RUB. BLOCK RETAINER CHANNEL LENGTH	3” – 15”

PIPE HANGER SUPPORTS



PIPE HANGER SUPPORT STRUCTURES ARE NOT CLASSIFIED AS AN INSTALLATION TYPE, SINCE THEY CAN BE INCLUDED IN MANY TYPES OF INSTALLATIONS. THE PARAMETER RANGES TO BE EVALUATED FOR SUPPORT STRUCTURES ARE :

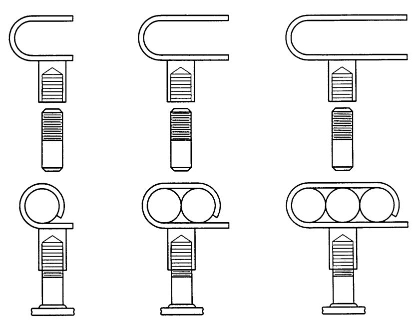
SUPPORT LENGTH	24” – 60”
SUPPORT ANGLE SIZES	2”×2”×0.1875” – 6”×4”×0.5”
PIPE CL AND SHIP STRUCTURE DISTANCE	18” – 48”
BRACE ANGLE (IF ANY)SIZES	2”×2”×0.1875” – 4”×4”×0.5”
BRACE LENGTH	18” – 48”
SUPPORT TO BRACE DISTANCE	24” – 48”
PIPE CL TO BRACE DISTANCE	6” – 12”

ELECTRICAL SYSTEMS

INDIVIDUAL PARAMETERS

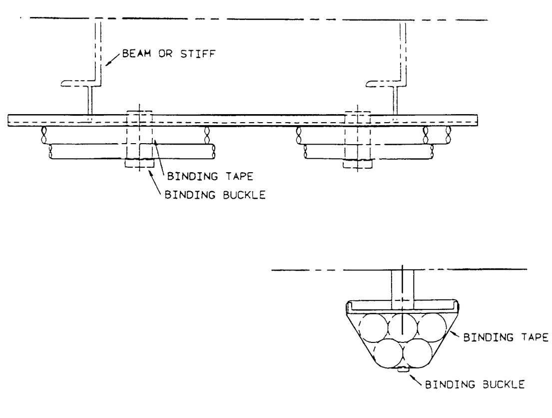
METHOD 1

NELSON STUD CABLE SUPPORT



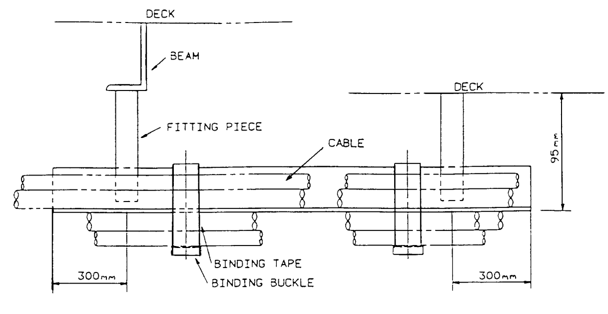
STUD LENGTH	3/16" – 6"
STUD DIAMETER	5/16" – ¾"
PLATING THICKNESS	3/16" – ¾"

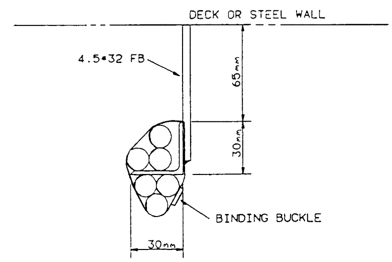
CH TYPE CABLEWAY



FLATBAR DIMENSIONS	2-1/2"×1-1/4"×3/16"–8"×4×1/2"
CHANNEL DIMENSIONS	C3×4.1 – C5×9
PLATING THICKNESS	3/16" – ¾"

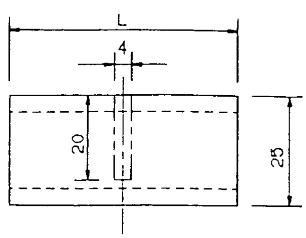
L-TYPE CABLEWAY

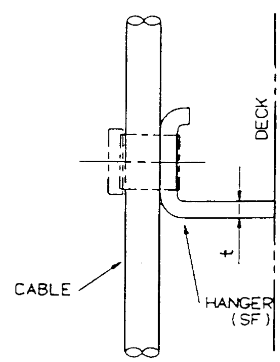


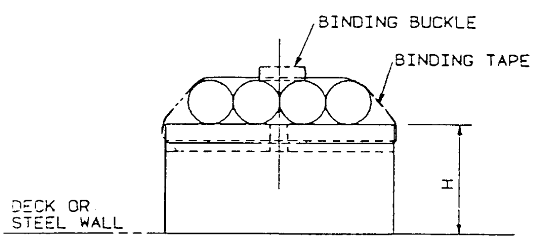


ANGLE DIMENSIONS	1”×1”×1/8”–2”×2”×1/4”
FLATBAR DIMENSIONS	2-1/2”×1-1/4”×3/16”–8”×4×1/2”
PLATING THICKNESS	3/16” – ¾”

HANGER-TYPE CABLEWAY SF, SH



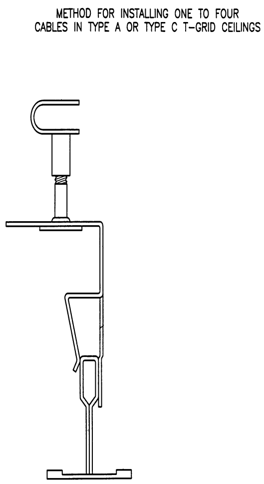


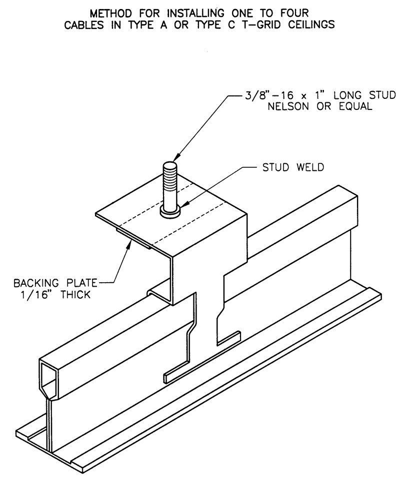


HANGER T	1/8”–1/4”
HANGER L	1-3/16” – 6”
HANGER H	1”–4”
PLATING THICKNESS	3/16” – ¾”

METHOD 2

TYPE A/C T-GRID CEILINGS

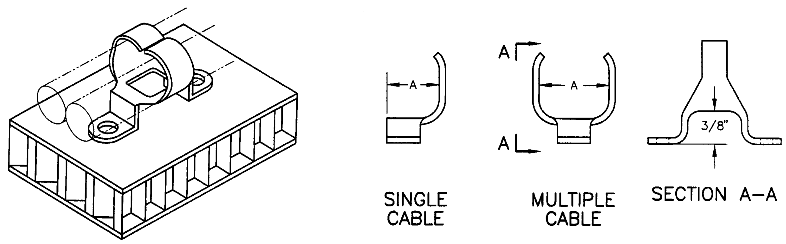




T-GRID THICKNESS	1/16” – 1/8”
BACKING PLATING THICKNESS	1/16” – 1/8”

METHOD 3

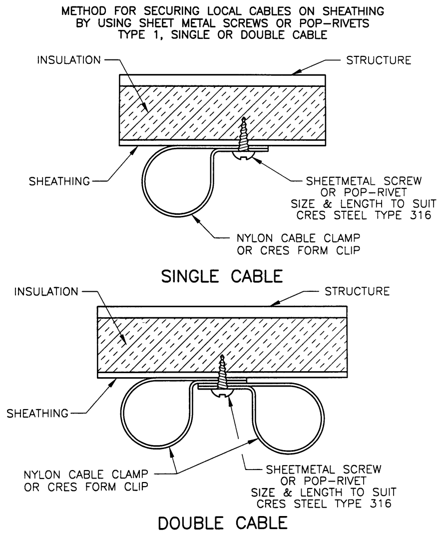
HONEYCOMB BULKHEAD HANGER



NO. OF LEGS	1 – 2
“A” DIMENSION (CLAMP WIDTH)	.3” – 2.2”
RIVET SIZE	4 – 6
NO. OF CABLES	1 – 4
STANDOFF DISTANCE	3/8” – 3”
PLATING THICKNESS	3/16” – ¾”

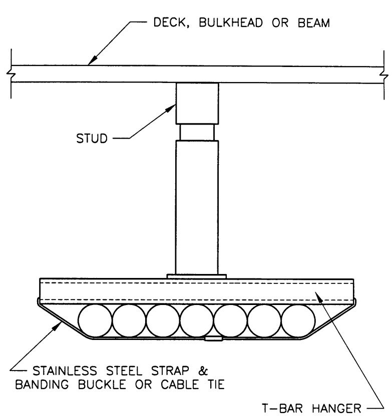
METHOD 4

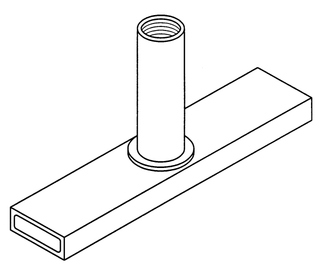
SECURING LOCAL CABLES ON SHEATHING



METHOD 5

TUBULAR HANGERS

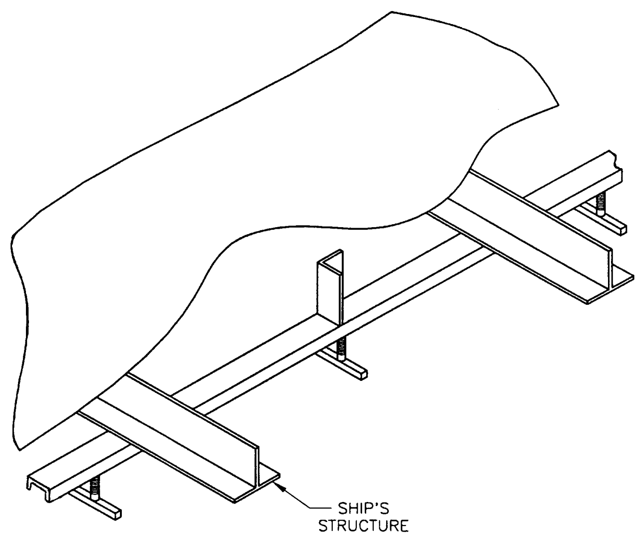




T-BAR SECTION	¼”×1/2” – ½”×1”
T-BAR LENGTH	1-1/2” – 7-1/2”
STUD DIAMETER	¼” – ¾”
STUD LENGTH	7/8” – 6”
PLATING THICKNESS	3/16” – ¾”

METHOD 6

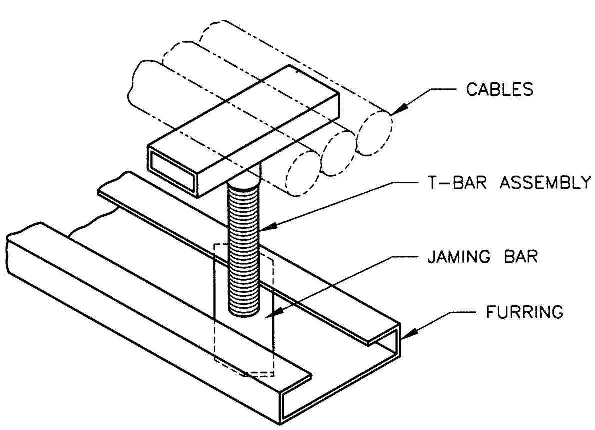
SUPPORTING T-BAR HANGERS ON BULKHEADS USING CHANNEL

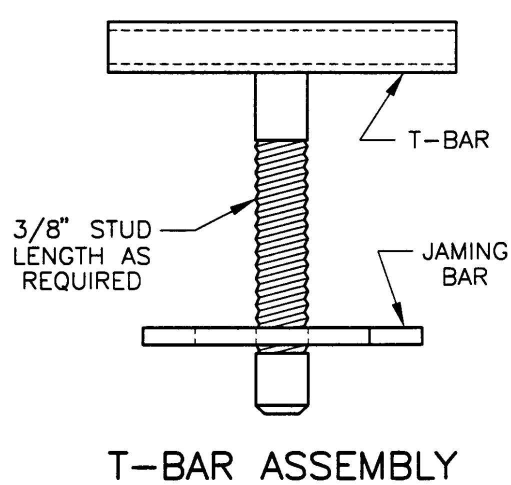


CHANNEL DIMENSIONS	1-1/2”×1/2”×1/8”–3”×1”×1/4”
ANGLE DIMENSIONS	1”×1”×1/8”–1-1/4”×1-1/4”×1/4”

METHOD 7

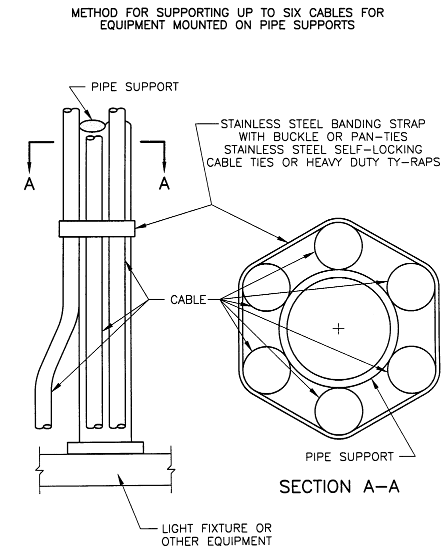
SUPPORTING CABLES RUNNING ON CEILING FURRING





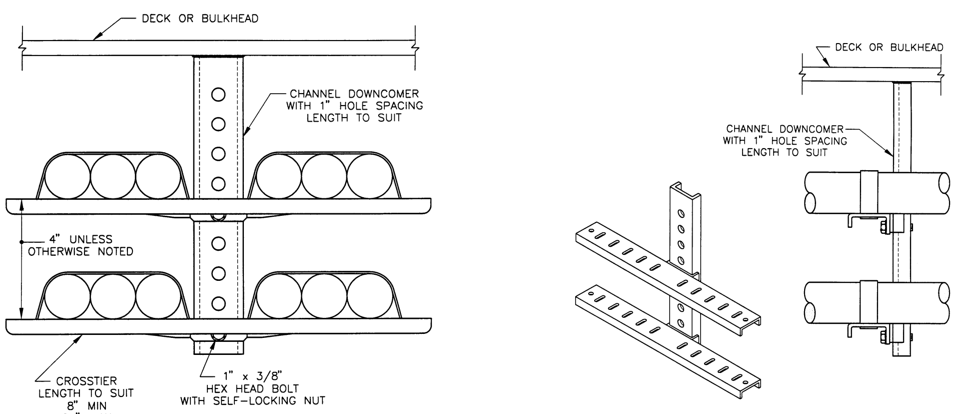
METHOD 8

CABLES MOUNTED ON PIPE SUPPORTS



METHOD 9

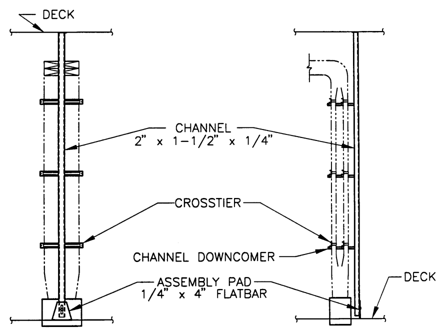
CROSSTIERS ON CHANNEL DOWNCOMER



DOWNCOMER DIMENSIONS	1-5/8”×5/8”×3/16”–2”×1”×1/2”
DOWNCOMER LENGTH	4”–30”
CROSSTIER DIMENSIONS	2-1/16”×1-1/8”×1/8”–3”×1-1/2”×1/4”
CROSSTIER LENGTH	8”–24”
PLATING THICKNESS	3/16”–3/4”

METHOD 10

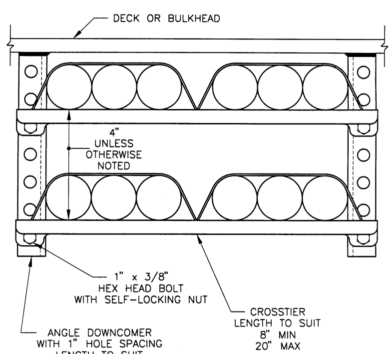
SUPPORTING VERTICAL TIERS OF CABLE INDEPENDENT OF SHIPS STRUCTURE WITH METHOD 9 HANGERS

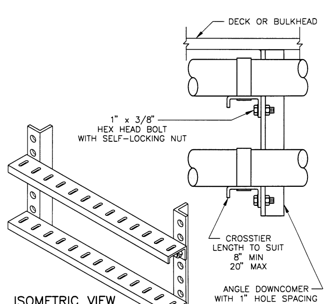


CHANNEL DIMENSIONS	2" X 1-1/2' X 1/4' TO 4" X 1-3/4' X 5/16"
CHANNEL LENGTH	2" TO 20'
ASSEMBLY PAD	1/4" X 4' TO 1/2' X 8"
PLATING THICKNESS	3/16" TO 3/4"

METHOD 11

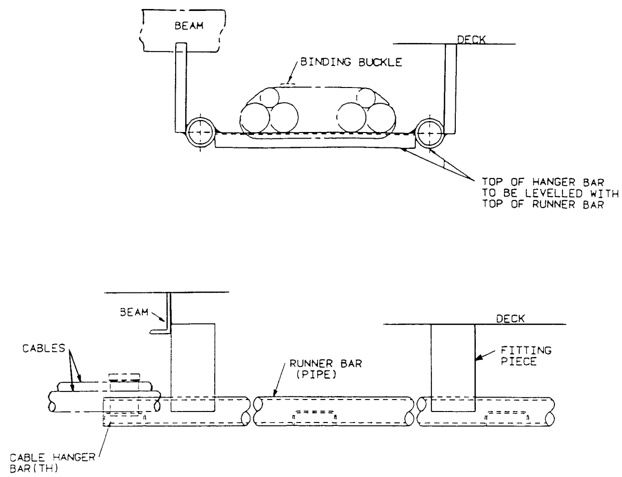
TRAPEZE TYPE CROSSTIERS AND CABLE TROUGHS





DOWNCOMER DIMENSIONS	1' X 1' X 3/16" TO 1-1/2" X 1-1/2" X 1/4"
DOWNCOMER LENGTH	3-3/8" TO 36-3/8'
CROSSTIER DIMENSIONS	2-1/16" X 1-1/8' X 1/8' TO 3" X 1-1/2" X 1/4"
CROSSTIER LENGTH	8" TO 20'
TROUGH LENGTH	6" TO 72"
PLATING THICKNESS	3/16' TO 3/4'

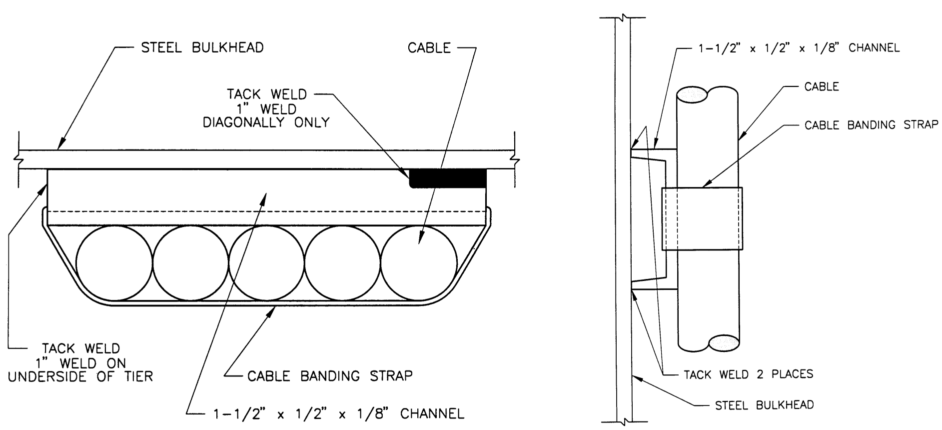
TRAPEZE WITH PIPE



FITTING PIECE DIMENSIONS	2" X 1/4' TO 4' X 1/2'
FITTING PIECE LENGTH	2" TO 20'
HANGER BAR DIMENSIONS	1' X 1' X 1/8" TO 2" X 2" X 1/4"
HANGER BAR LENGTH	8" TO 20"
RUNNER BAR SECTION	1" O.D. TO 4' O.D.
RUNNER BAR LENGTH	6" TO 72"
PLATING THICKNESS	3/16" TO 3/4'

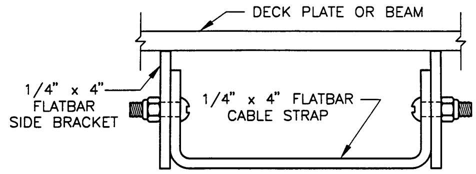
METHOD 12

SUPPORTING CABLES IN DECKS AND BULKHEADS WHERE WIREWAY SPACE IS LIMITED



METHOD 13

SUPPORTING CABLES WITH PORTABLE FLATBAR U-BRACKET



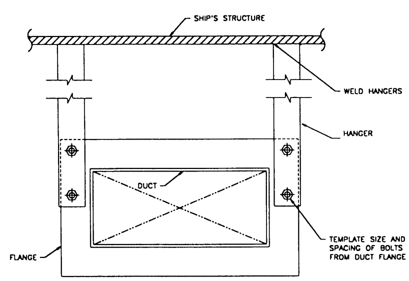
FLATBAR DIMENSIONS	1/4" X 4" TO 1/8" X 4"
FLATBAR LENGTH	2" TO 3'
U-BRACKET SECTION	1/4" X **4"** TO 1/8' X 4'
U-BRACKET LENGTH	8" TO 20"
U-BRACKET DEPTH	4" TO 36'
PLATING THICKNESS	3/16" TO 3/4"

VENTILATION / DUCTING SYSTEMS

INDIVIDUAL PARAMETERS

METHOD 1

ANGLE/FLAT BAR DOWN-COMER HANGERS

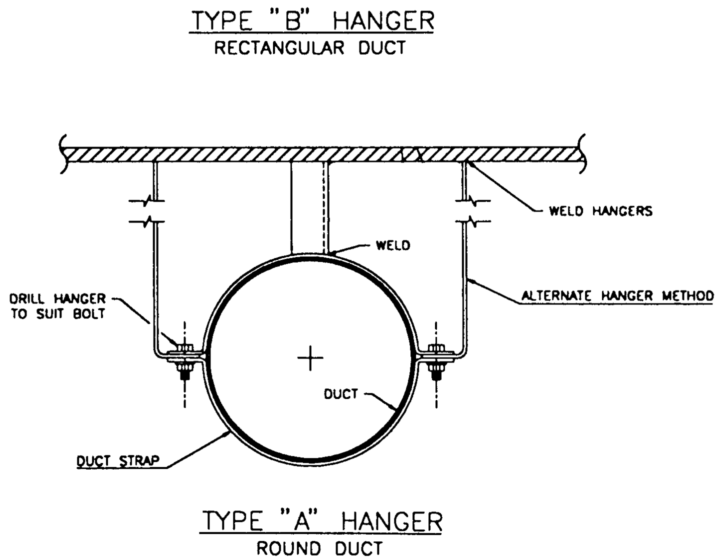


TYPE "B" HANGER
RECTANGULAR DUCT

DOWN-COMER ANGLE SIZES	1.25”×1.25”×0.1875” – 3”×3”×0.375”
DOWN-COMER FLAT-BAR SIZES	1.5”×0.25” – 4”×0.5”
DOWN-COMER LENGTH	6” – 48”
LATERAL SPACING BETWEEN DOWN-COMERS	12” – 48”

BOLT SIZE	0.25” – 0.625”

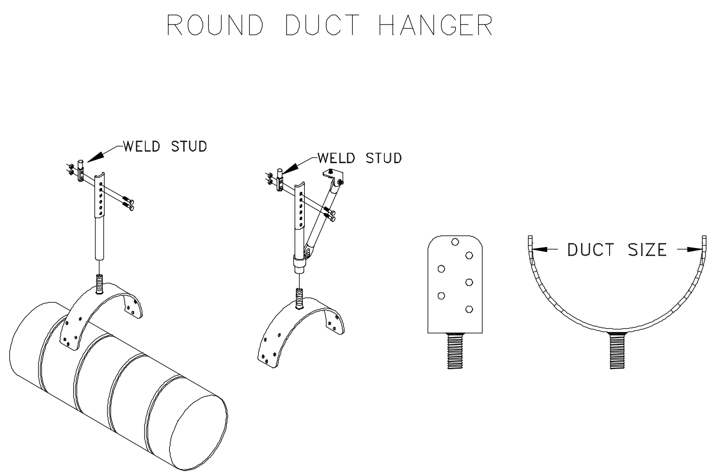
ANGLE / FLAT BAR DOWN-COMER W/ CLAMPS HANGERS



SAME AS ANGLE / FLAT BAR DOWN-COMER HANGERS	
CLAMP / STRAP FLAT-BAR SIZES	1”×0.125” – 2”×0.25”

METHOD 2

RTD DUCT HANGERS



HANGER BODY FLAT BAR	2”×0.25” – 4”×0.5”
STAND-OFF STEEL PIPE LENGTH	6” – 36”
STAND-OFF STEEL PIPE SIZES	SAME AS RTD PIPE HANGERS
HANGER TO DUCT ATTACHING BOLT SIZE	0.25” – 0.625”
BRACE (IF ANY) LENGTH	18” – 30”
BRACE PIPE SIZE	SAME AS RTD PIPE HANGERS
STAND-OFF TO SHIP STRUCTURE CONNECTING STUD SIZE	SAME AS RTD PIPE HANGERS
BRACE TO SHIP STRUCTURE CONNECTING STUD SIZE	SAME AS RTD PIPE HANGERS
BRACE TO STAND-OFF CONNECTING BOLT SIZE	SAME AS RTD PIPE HANGERS

RTD LARGE VENT HANGERS

SAME AS RTD DUCT HANGERS

METHOD 3

RESILIENT DUCT HANGERS	
DOWN-COMER FLAT BAR SIZES	1.25”×0.1875” – 2.5”×0.3125”
DOWN-COMER ATTACHMENT STUD SIZES	0.25” – 0.5”
DUCT CLAMP FLAT BAR WIDTH AND THICKNES	SAME AS DOWN-COMER W/ CLAMPS HANGERS
DUCT CLAMP FASTENING BOLT SIZE	SAME AS DOWN-COMER W/ CLAMPS HANGERS

The parameters of various system installation types and their respective min/max and ranges will be used as the starting point for the engineering analysis and standards development.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 5 — ENGINEERING, TESTING, AND VALIDATION METHODOLOGY

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TABLE OF CONTENTS

5.A ESTABLISH ENGINEERING, TESTING, AND VALIDATION METHODOLOGY FOR EQUIPMENT INSTALLATIONS

Under this task we have looked at the engineering criteria, specifications and requirements, and the design and fabrication attributes for cost reduction and producibility, and we have framed up an integrated set of procedures to conduct engineering analyses and verification of the standards to be proposed later in the project. This sub-task report describes and outlines this engineering methodology. This section also elaborates the loading criteria, failure criteria and allowable limits to be used in the standards development calculations.

Standard equipment foundations are categorized into 27 representative foundation designs, 18 standard method mounts, Spool mounts and Stud Mounts, as described under sub-task 4.A. The Shipboard Modular Arrangement Reconfiguration Technology (SMART) Systems from Affordability Through Commonality (ATC) for equipment foundation system will also be evaluated and incorporated, as required. The SMART system utilizes a 2-dimensional installation plane incorporating components like parallel tracks, foundation adapters, and foundation sub-assemblies, spread over the area of interest. This provides the equipment installer with the flexibility to install equipment at any orientation and desired location in the area of interest, without needing to design and integrate the foundations with the ship structures. The area of interest can be either decks or bulkheads.

Analysis of the foundation types will be conducted for only certain candidate foundation types. These candidate foundation types are such that, they or variations of them will represent all of the standard foundation types mentioned above. During the course of development of the standards a parametric analysis approach to foundation design will be adopted and used.

Foundation installation statistics reveal that the variety of combinations of geometries and equipment weights is limited and can be clearly defined. Utilization of a parametric analysis approach provides solutions for broad ranges of possibilities at one time, rather than each time the possibility is encountered, which can be drawn upon later to significantly reduce engineering and design time. Standard foundation designs could be developed which satisfy a wide variety of applications. In the final standards development, design data tables and view-graphs for foundations will be included which would allow the engineer to quickly determine if a foundation sketch proposed by the designer is adequate enough by comparison, rather than by performing the detailed analysis for the same scenario repeatedly.

The design data tables of the standards will be generated for commercial applications. In case of naval ships where shock, nuclear blast, noise, and other criteria predominantly govern the foundation design, foundation design validation through standard designs can still be accomplished by performing a parametric approach to foundation analysis and obtaining standard design tables for foundations based on the navy ship requirements and specifications. To validate the initial foundation design the engineer can verify the foundation geometries and scantling sizes with design data tables for adequacy, provided the requirements, specifications and allowables are similar to that used in this standards development. If the requirements and allowables vary then the engineer can scale the foundation geometries and scantling sizes accordingly.

The engineering analysis will be done under four (4) primary categories of foundation/installation, namely

1. Grillages
    a) Grillage welded to mounting plate
    b) Grillage lifted off mounting plate
    c) Overhanging Grillage
    d) Method Mountings
2. Frames and Trusses
3. Stud Mountings

a) Single Stud

b) Multiple Studs

4. Spool Mountings

c) Single Spool

d) Multiple Spools

METHOD OF ANALYSIS

Allowable weight for a given foundation type will be determined based on a number of different failure criteria, all of which fall into two categories, strength criteria and frequency criteria. Finite Element Models and Spreadsheets will be created to calculate the weight limits based on each criteria for a large envelope of foundation configurations. For each configuration, the lowest allowable weight from the most limiting criteria will be used for that specific foundation. The allowables for each of these criteria are calculated using conservative methods, loads and assumptions as described further.

LOADING

Loads are induced into foundation scantlings through the equipment attachments. Ship's motion loads on the equipment, measured in terms of equivalent static G's, are applied to the equipment and the resultant forces are resolved at the attachments. Acceleration values, based on a worst case scenario, of 3 G's vertical, 1.5 G's transverse and 0.75 G's longitudinal are applied to the equipment simultaneously. Combined with the equipment weight, these accelerations produce forces on the equipment acting in all three directions.

In calculating resultant forces at the foundation attachments the number of attachments/ bolts on the scantling span will not be considered, instead a worst case assumption will be made that each scantling span had only two effective bolts. For example, axial and shear forces will be computed as if there is only one bolt on either scantling of a foundation span. Overturning forces will be computed based on the *e/h* of the equipment and distributed on the foundation spans as if they are supported by only one bolt. Since forces are acting in three directions, there are two directions which produce overturning forces and in reality two different equipment *e/h*'s to consider, but to be conservative the minimum of the two values, producing the higher resultant force for a given load, will be used for both directions of overturning. Additionally, the worst conceivable load at the bolt will be calculated by orientating the foundation so that the ship's motion loads produce the highest bolt loads. Figure 5-1 shows the resolved forces for a particular grillage configuration.

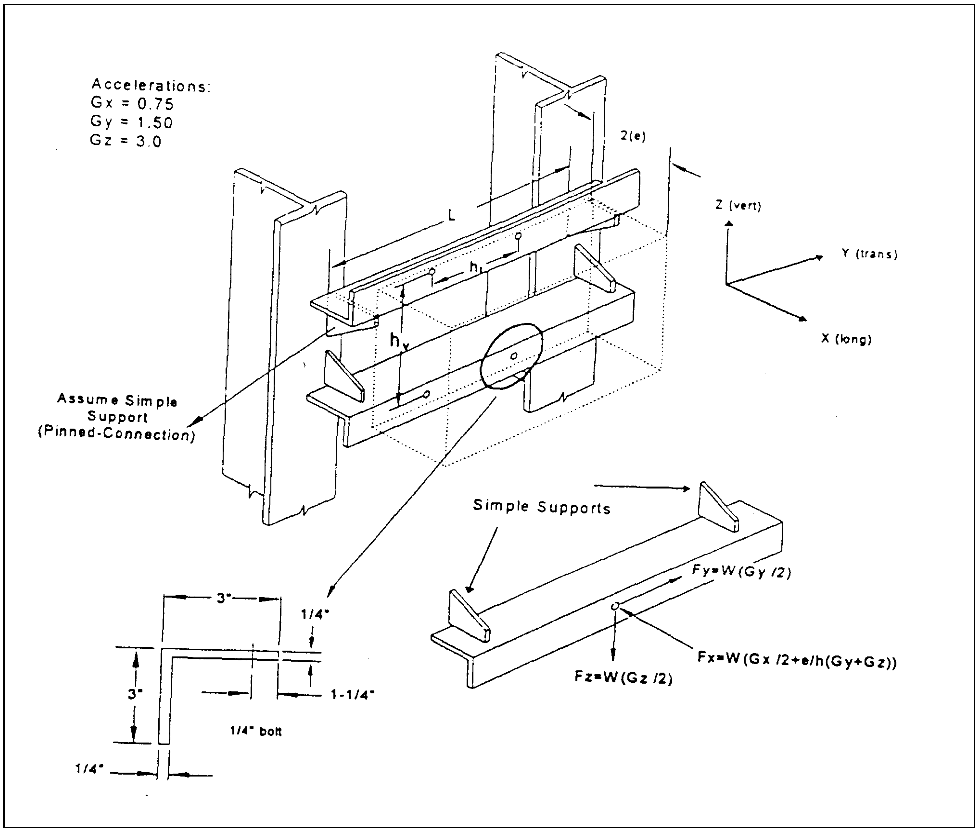


Figure 5-1 — Resolving of Grillage Forces

FAILURE CRITERIA

STRENGTH

Based on the worst foundation configurations and loads, stresses will be computed for all possible failure modes. Failure is assumed to occur through yield failure in one or all of the scantlings, or by local yield failure in way of one or more bolts. All stresses will be computed at their worst location, the spot on the foundation where the biggest force or moment occurs.

Angle stresses will be calculated using beam formulae. Critical stress occurs in a scantling as a result of both bending and axial loads in the beam. Bending stresses will be combined for bi-axial bending, where the stress at the toe of the angle from one direction of bending will be added to the stress at the heel from the other direction of bending and vice-versa. This worst bending stress will then be combined with the nominal axial stress calculated from the highest axial load in the foundation scantling/angle and the corresponding cross-sectional area.

Figure 5-2, shows graphically the various local attachment failure criteria. Bolt attachment will be checked for all modes of shear, bearing and bending. All calculations will be performed assuming 1/4" bolts, because this is the smallest bolt size any equipment would generally need and smaller bolts produce higher stresses for all failure modes. Shear failure can either occur perpendicular to the angle flange due to axial bolt loads or parallel to the flange from shear loads in the bolt. Bearing stress is a nominal stress computed from the cross-sectional area of the bolt hole.

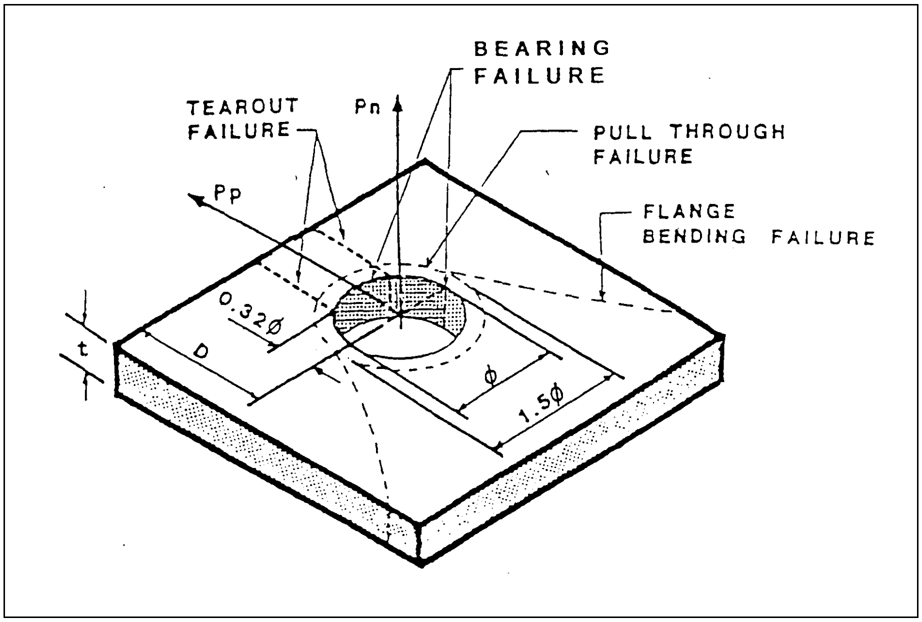


Figure 5-1 — Foundation Bolting Plate

where,	Pn	=	Bolt load normal to the plate
	Pp	=	Bolt load parallel to the plate
	t	=	plate thickness
	ϕ	=	Bolt diameter
	D	=	Edge distance

Flange bending is the result of the moment created between the centerline of a bolt and the heel of the angle. The greater the bolt distance from the heel, the greater the flange bending moment. So to be conservative, the bolt will be assumed to land at its furthest possible location from the heel i.e. approximately 35 to 40% of the flange width from the toe of the angle. The moment produced is resisted partially at the bolt and partially at the angle heel depending on the condition of fixity at those locations. The most conservative assumption for moment distribution will be assumed, which is when the equipment is always clamped to the flange at the bolt and the heel is partially free, putting 80% of the moment at the bolt and 20% at the heel.

FREQUENCY

For all foundations, it is important to insure that the lowest natural frequency of vibration of the foundation is greater than the excitation frequency of the propeller. The natural frequency will be checked for several modes of vibration, and the lowest natural frequency of the foundation will be compared to the allowable frequency. Springs included in the natural frequency calculation for a foundation are the bending of the scantling, in two directions, and the flexibility of the flange. Torsion flexibility of the mounting scantlings will be disregarded because of the assumption that the flange is clamped to the equipment. Three different vibration modes will be calculated for foundations, i.e. parallel to the mounting plane, perpendicular to the mounting plane, and due to over-turning motion of the equipment.

When a foundation does not fully land on rigid ship structure, it is necessary to check the natural frequency of the foundation coupled with the vibration of the mounting plate. It is no longer necessary

to include the angle as a spring in the vibration calculation, thus the springs for this natural frequency calculation will be the flange flexibility and the out-of-plane bending of the mounting plate. The natural frequency will be calculated for the perpendicular and over-turning modes of vibration.

ALLOWABLES

STRESS

The stress allowables are based on the assumptions that scantlings are of mild steel and studs are of high strength steel, having yield strength and tensile strength of 34 KSI and 50 KSI, respectively.

NOMINAL TENSILE STRESS ALLOWABLE IS 80% OF YIELD STRENGTH	27.2 KSI
SHEAR STRESS ALLOWABLE IS 60% OF TENSILE ALLOWABLE	16.3 KSI
BEARING STRESS ALLOWABLE IS 80% OF TENSILE ALLOWABLE	21.8 KSI
STRESS ALLOWABLE FOR STUDS IS 60% OF TENSILE STRENGTH	30.0 KSI

FREQUENCY

Based on the propeller excitation frequency of 12 Hz, which is found mostly in vessels of higher speeds, the allowable natural frequency for the foundations is kept 25% higher than the propeller excitation frequency. Thus, the allowable frequency to be used to obtain the values in design data tables will be 15 Hz.

FOUNDATION CONFIGURATION

GRILLAGES

Three different types of grillage configurations will be considered for the calculations, namely: Grillage welded to mounting plate; Grillage lifted off mounting plate; Overhanging Grillage. Method Mountings are extensions or combinations of these three primary configurations. The allowable weights for the standards will be obtained using a spreadsheet approach to check for the various failure criteria for 6 different angle sizes, for 2 cases of *e/h* ratios. Figure 5-3 shows the Grillage Off-deck and Overhanging Grillage configurations.

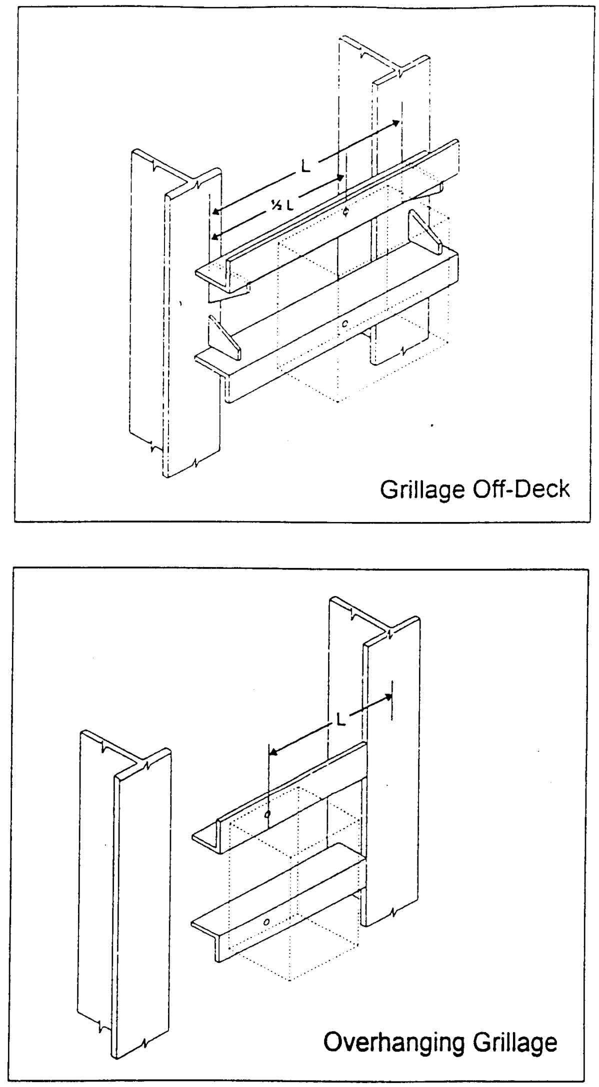


Figure 5-1 — Grillage Off-deck and Overhanging Grillage Configurations

FRAMES / TRUSSES

Various configurations of Frames and Trusses will be analyzed using finite element models (FEM) for 5 different angle sizes, for 2 cases of e/h ratios. The FEMs will be run for the worst combination of G loadings, and the effect of overturning of equipment will also be included. All the models will be of 4 equal size legs, and the mounting attachments (bolt locations) will be assumed to be at the four corners of the mounting plane. The results of FEMs will be used to obtain the allowable weight capacity for the legs of the frames and trusses. A Grillage spreadsheet approach will be used to obtain the allowable weights for mounting scantlings.

STUDS

Studs of various lengths and sizes varying from 5/16" to 3/4” will be analyzed using a spreadsheet approach, to obtain the allowable weight capacities. The worst combination of G loading on two configurations will be analyzed, namely: single stud, and multiple studs (4 studs). In the case of single stud configuration, the varying stand off length is considered from the base of the stud to the C.G. of the equipment, thus taking equipment overturning into consideration. Whereas, for the multiple stud configuration the varying stand off length is the actual stud length, and the equipment overturning is assumed to be restrained.

Both vibration and strength limiting criteria will be checked. Under vibration, frequency due to out-of-plane mounting plate bending, and frequency due to stud and stud/plate connection bending will be checked. Under strength limitation, studs by themselves will be checked for axial plus bending stresses. Further, the stud/plate connection will be analyzed using Roark's equation ("Roark's Formula for Stress and Strain", Warren C. Young, 6th edition, pg. 435, 1989), using various plate thickness.

SPOOLS

Spools of sizes 2.5” and 4” dia. with various lengths will be analyzed using a spreadsheet approach, to obtain the allowable weight capacities. Spools of varying lengths can be obtained by connecting multiple spools end-to-end till the desired length is obtained. The analysis methods described for studs will also be used for spools. In addition to the strength and frequency calculations mentioned for the studs, strength adequacy checks for the spools themselves will also be performed.

5.B ESTABLISH ENGINEERING AND VALIDATION METHODOLOGY FOR DISTRIBUTIVE SYSTEM INSTALLATION

The first step in deriving an engineering methodology or analysis method is to review the engineering criteria and design and fabrication attributes from the previous section. After further review of several of the cost reducing and producibility measures, an analysis plan was formulated. The end result of the engineering should result in a system highly conducive to an automated hanger selection process for pipe, electrical, and HVAC/duct disciplines. This sub-task report describes and outlines this engineering methodology. This section also elaborates the loading criteria, failure criteria and allowable limits to be used in the standards development calculations.

The initial goal of the analysis is to develop a set of tables, charts, or spreadsheets from which a hanger type and size can be selected given a string of input data. The available hanger type and size will be chosen from a distilled list of appropriate, cost saving, and producible hangers. This table of candidate hangers will be assembled as the engineering analysis moves forward.

A logical solution to the above goals would be to achieve a parametric spread of variables for each selected hanger type. Each chosen variable will have an acceptable range for that particular hanger type and size. For instance, a hanger may be able to support anywhere from 1 to 40 Lbs. and has a standoff distance from 1 to 6 inches. The initial variables for which parametric ranges will be implemented are:

- Pipe/cable size

- Pipe/cable weight
- Weight of valves, fittings, etc.
- # of pipes/cables
- Standoff distance
- Hanger spacing

Given the above input criteria for a given system, it is a simple task for a designer to choose a hanger that satisfies the conditions. In some cases, more than one hanger may be acceptable for a certain situation. If this happens, a secondary set of criteria will be considered. This criteria will involve cost factors, producibility factors, and location factors. Thus, a hanger, which is more conducive to a particular area and more cost effective, can be used.

These parametric ranges will define and make-up design data tables which will be part of the installation standards. The ranges will be produced by a variety of engineering methods. For existing hanger types, the ranges will be determined by utilizing existing standards and vendor furnished information. For new and innovative hangers, the ranges will result from a combination of hand calculations, spreadsheets, and some limited FEM analysis. This analysis will also validate the new standards. These design data tables will be developed for commercial applications, and will be comprised of pipe hangers, electrical hangers, and HVAC/duct hangers.

METHOD OF ANALYSIS

The detailed analysis will begin by choosing a collection of core candidates for electrical, piping, and HVAC components. As each iteration takes place, this initial list may be altered and updated. As the process continues, innovations in design can be applied and possibly adopted depending on results. The final compilation will be an acceptable list of new standards. The envisioned analysis effort will be both for a static case and a dynamic or modal case. In addition, the work will be further broken out to look at the case of a single hanger supporting a point load and the case of multiple hangers supporting a rigid pipe or a series of cables acting in unison.

The static case will look at the hangers' capability of supporting weight. Standoff will be a major variable, as the loads will have all three directional components. In the static cases, close attention will be paid to the attachment techniques and strength. Here it will be determined, on a case by case basis, whether a hot weld attachment or a cold pre-outfit method mount / fastener is preferable. These results balanced with cost savings and producibility could define a new manufacturing and installation procedure.

The dynamic or modal analysis will look more at resulting system stiffness and corresponding frequency. Care will be taken to avoid frequencies that coincide with blade rate or reciprocating machinery. The different frequencies produced by rigid pipe and non-rigid cableways will both be considered. This quasi-static approach assuming linear elastic behavior will be used to solve what is essentially a non-linear problem, and will obtain results that are fairly conservative. This analysis will be performed using both spreadsheets and FEA software.

Allowable weight for a given installation type will be determined based on a number of different failure criteria, all of which fall into two categories, strength criteria and frequency criteria. Finite Element Models and Spreadsheets will be created to calculate the weight limits based on each criterion for a range of core installation configurations. For each configuration, the lowest allowable weight from the most limiting criteria will be used for that specific installation. The allowables for each of these criteria are calculated using conservative methods, loads and assumptions as described further.

LOADING

Loads are induced into installation scantlings through the system attachments. Ship's motion loads on the system runs, measured in terms of equivalent static G's, are applied to the system and the resultant forces are resolved at the attachments. Acceleration values, based on a worst case scenario, of 3 G's vertical, 1.5 G's transverse and 0.75 G's longitudinal are applied to the system simultaneously. Combined with the weight of the system along with the fluid its carrying, these accelerations produce forces on the system run acting in all three directions.

In calculating resultant forces at the installation attachments, a worst case assumption of the number of effective bolts will be made. Additionally, the worst conceivable load at the bolt will be calculated by orientating the installation so that the ship's motion loads produce the highest bolt loads.

FAILURE CRITERIA

STRENGTH

Based on the worst installation configurations and loads, stresses will be computed for all possible failure modes. Failure is assumed to occur through yield failure in one or all of the scantlings, or by local yield failure in way of one or more bolts. All stresses will be computed at their worst location, the spot on the installation where the biggest force or moment occurs. Angle stresses will be calculated using beam formulae. Critical stress occurs in a scantling as a result of both bending and axial loads in the beam.

Figure 5b-1, shows graphically the various local attachment failure criteria. Bolt attachment will be checked for all modes of shear, bearing and bending. All calculations will be performed assuming the smallest of the allowed bolts, because smaller bolts produce higher stresses for all failure modes. Shear failure can either occur perpendicular to the flange due to axial bolt loads or parallel to the flange from shear loads in the bolt. Bearing stress is a nominal stress computed from the cross-sectional area of the bolt hole.

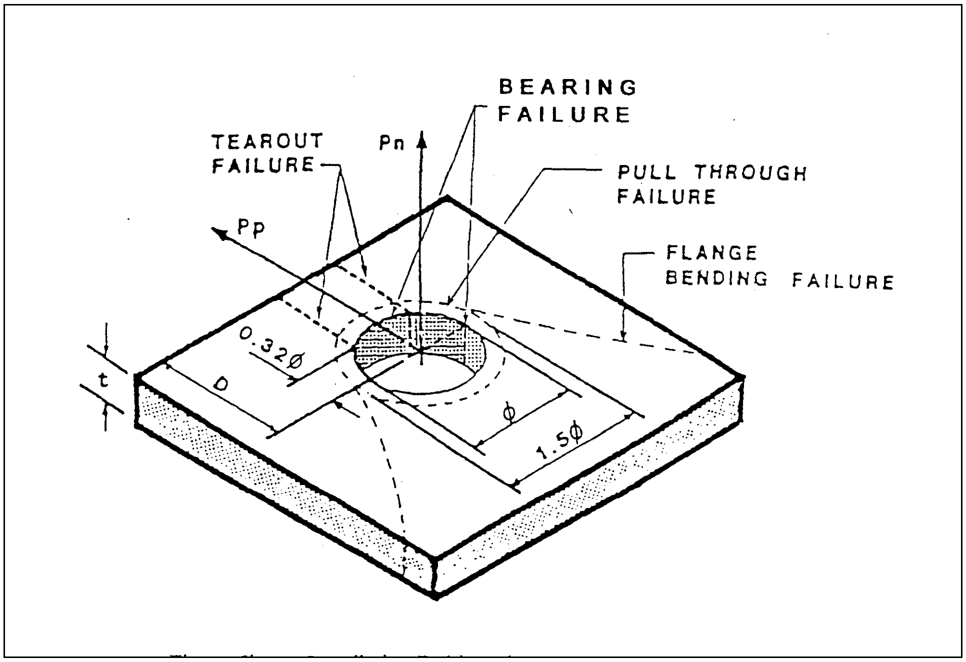


Figure 5-1 — Installation Boring Plate

where,	Pn	=	Bolt load normal to the plate
	Pp	=	Bolt load parallel to the plate
	t	=	plate thickness
	ϕ	=	Bolt diameter
	D	=	Edge distance

FREQUENCY

For all installations, it is important to insure that the lowest natural frequency of vibration of the installation is greater than the excitation frequency of the propeller. The natural frequency will be checked for several modes of vibration, and the lowest natural frequency of the installation will be compared to the allowable frequency. Springs included in the natural frequency calculation for a system installation are the bending of the scantling, in two directions, and the flexibility of the stiffener flange or deck/bulkhead plating. Torsion flexibility of the stand-off / downcomer scantlings will also be included. For multiple hangers, the asymmetric vibration mode that gives the lowest natural frequency will be calculated first, then higher modes will be checked into.

When an installation does not fully land on rigid ship structure, it is necessary to check the natural frequency of the installation coupled with the vibration of the deck/bulkhead plating. The springs for this natural frequency calculation will be the clamp flexibility and the out-of-plane bending of the mounting plate.

ALLOWABLES

STRESS

The stress allowables are based on the assumptions that scantlings are of mild steel and studs are of high strength steel, having yield strength and tensile strength of 34 KSI and 50 KSI, respectively.

NOMINAL TENSILE STRESS ALLOWABLE IS 80% OF YIELD STRENGTH	27.2 KSI
SHEAR STRESS ALLOWABLE IS 60% OF TENSILE ALLOWABLE	16.3 KSI
BEARING STRESS ALLOWABLE IS 80% OF TENSILE ALLOWABLE	21.8 KSI
STRESS ALLOWABLE FOR STUDS IS 60% OF TENSILE STRENGTH	30.0 KSI

FREQUENCY

Based on the propeller excitation frequency of 12 Hz, which is found mostly in vessels of higher speeds, the allowable natural frequency for the installations is kept 25% higher than the propeller excitation frequency. Thus, the allowable frequency to be used to obtain the values in design data tables will be 15 Hz.

The initial core list of electrical hangers include the following types:

- Nelson Stud
- CH Type
- L Type
- Honeycomb Bulkhead Hanger
- Tubular Hangers (with and without channel support)
- Crosstiers on Channel Downcomers
- Trapeze Type Crosstiers and Cable Troughs
- Flatbar U-bracket

The initial core list of Pipe hangers include the following types:

- U-Bolt Assembly
- U-Bolt Assembly w/ Stan-off or Stool
- Clamp Hangers
- Clamp and Channel Hangers
- Full Cap /Band Hangers
- Single Leg “L” Band Hanger
- RTD Stud Hangers

- Nelson Type Hangers
- Rubber Block Hangers

The initial core list of Ventilation/Ducting hangers include the following types:

- Angle / Flat Bar Down-Comer Hangers
- Angle / Flat Bar Down-Comer w/Clamps Hangers
- RTD Duct Hangers
- Resilient Duct Hangers

APPENDIX A — SHIP'S MOTIONS ACCELERATIONS

VIBTECH, INC.	CALCULATION NO.	
TITLE: Dynamic Load Calculations	CALC. BY SLJ	DATE 8/15/95
	PROJECT 95-040	SHT 1 OF 1

Dynamic Loads Calc
from SLNC Ship Specification

Assume $x = 400'$
$y = 45'$
$z = 60'$

Vertical: (Light)

$$G's = 1.0 + .2 + .0017(x) + .0037(y)$$
$$= 1.0 + .2 + .0017(400) + .0037(45)$$
$$= 1.0 + .2 + .68 + .167 = \underline{\underline{2.05}}$$

Transverse: (Light)

$$G's = .52 + .00084(x) + .002(y) + .0037(z)$$
$$= .52 + .00084(400) + .002(45) + .0037(60)$$
$$= .52 + .336 + .09 + .222 = \underline{\underline{1.17}}$$

Longitudinal:

$$G's = .19 + .00015(x) + .0017(z)$$
$$= .19 + .00015(400) + .0017(60)$$
$$= .19 + .06 + .102 = \underline{\underline{.352}}$$

To be conservative use:

$G_V = 2.5$
$G_T = 1.25$
$G_L = 0.5$

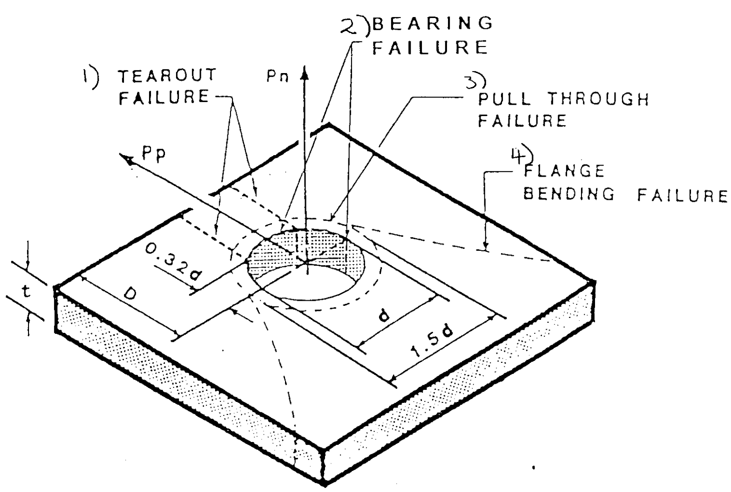
Figure 5-1 — Dynamic Load Calculations

APPENDIX B — BOLT ATTACHMENT CALCUALTION METHODS

VIBTECH, INC.	CALCULATION NO.	
TITLE: Bolt Attachment Calculation Methodology	CALC. BY SLJ	DATE 8/15/95
	PROJECT 95-040	SHT 1 OF 11

There are 4 potential failure modes on the flange in way of the bolts.

SKETCH SHOWING 4 MODES OF FLANGE FAILURE



FOUNDATION BOLTING PLATE

P_N = bolt load normal to the plate
P_p = bolt load parallel to the plate
t = plate thickness
d = bolt diameter
D = edge distance

Figure 5-1 — Four Modes of Flange Failure

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 2 OF

Shear Tearout Calc. Method:

Fig. D1.9

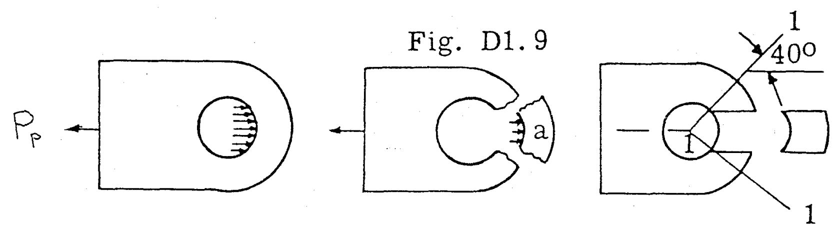


Fig. a Fig. b Fig. c

$$\tau_{Tearout} = \frac{P_p}{A_{shear}}$$

$$A_{shear} = 2(D - 0.32d)t$$

$$\tau_{Tearout} = \frac{P_p}{2(D-0.32d)t}$$

Figure 5-2 — Shear Tearout Calculation Method

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 3 OF

Bolt Bearing Calc. Method:

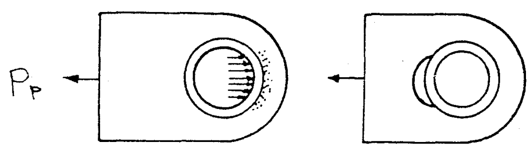


Fig. a   Fig. b   Fig. D1. 10

$$\sigma_{Bear} = \frac{P_p}{A_{Bear}}$$

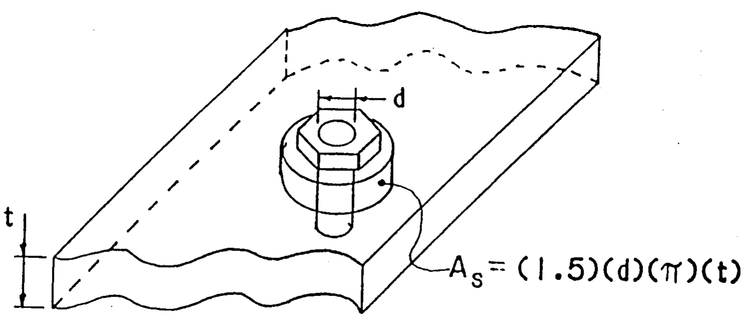
$$A_{Bear} = d \cdot t$$

$$\sigma_{Bear} = \frac{P_p}{d \cdot t}$$

Figure 5-3 — Bolt Bearing Calculation Method

VIBTECH, INC.	CALCULATION NO. ______	
TITLE: ______	CALC. BY	DATE
______	PROJECT	SHT 4 OF ___

Bolt Pull Through Calc. Method:



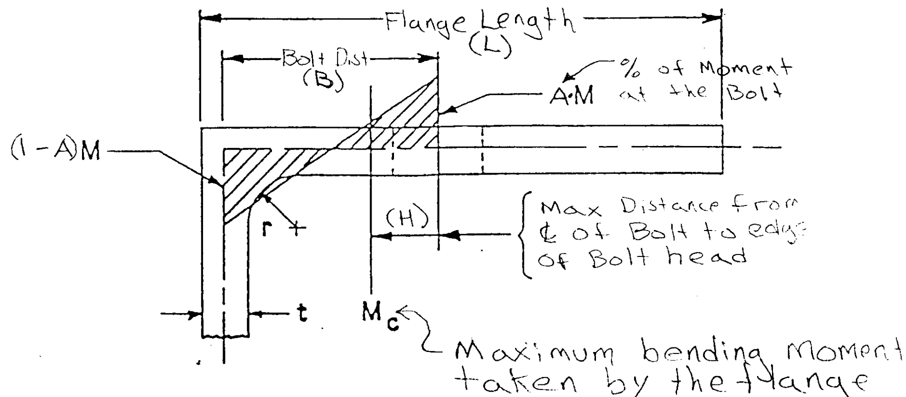
$$\tau_{Pull\ Through} = \frac{P_N}{A_s}$$

$$\tau_{Pull\ Through} = \frac{P_N}{1.5\, d \pi t}$$

Figure 5-4 — Bolt Pull Through Calculation Method

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 5 OF

Flange Bending Calc. Method:



$$M = P_n \cdot B$$

Ratio the moment arms to get the critical moment (M_c) at the bolt head edge.

$$\frac{M_c}{A \cdot B - H} = \frac{A \cdot M}{A \cdot B}$$

$$M_c = \frac{(A \cdot B - H)\, M}{A \cdot B} = \frac{(A \cdot B - H)\, \cancel{A} \cdot P_n \cdot \cancel{B}}{\cancel{A} \cdot \cancel{B}}$$

$$M_c = P_n (A \cdot B - H)$$

This moment can be used to calculate a nominal flange bending stress.

$$\sigma_{Flg\ bend} = \frac{M_c}{Z}$$

To determine Z, it is necessary to find the length of flange which is effective in bending.

Figure 5-5 — Flange Bending Calculation Method

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 6 OF

Determine the portion of the flange that is effective in bending:

$$\sigma_{\substack{Bend\\Flg}} = \frac{Mc}{Z}$$

$M_c = P_n(0.5B - H)$, for a flange with clamping at the heel (A = 0.5).

$$Z = \frac{I}{y}$$

$$I = \frac{bh^3}{12} = \frac{(XF)(t^3)}{12}$$ where X is the effective portion of the flange

$$y = \frac{t}{2}$$

$$Z = \frac{\frac{(XF)t^3}{12}}{\frac{t}{2}} = \frac{XFt^2}{6}$$

$$\sigma_{\substack{Bend\\Fly}} = \frac{6 \cdot P_n(0.5B - H)}{XFt^2}$$

Using finite element models it is possible to determine the stress at the bolt and the plug this into the equation above in order to solve for X.

$$X = \frac{6P_n(0.5B - H)}{\sigma(\text{from Model})\, Ft^2}$$

Finite element models were created for different flange bending cases to determine an X applicable to all bolt critical flange bending cases.

Figure 5-6 — Sheet 6 of 11

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 7 OF

Finite Element Model Details:

3" Flange; 0.25" thick
℄ Bolt 2.625" from the heel

$F = 3"$
$B = 2.5"$
$t = 0.25"$
$P_n = 1000$ lbs.
$H = 0.1875"$

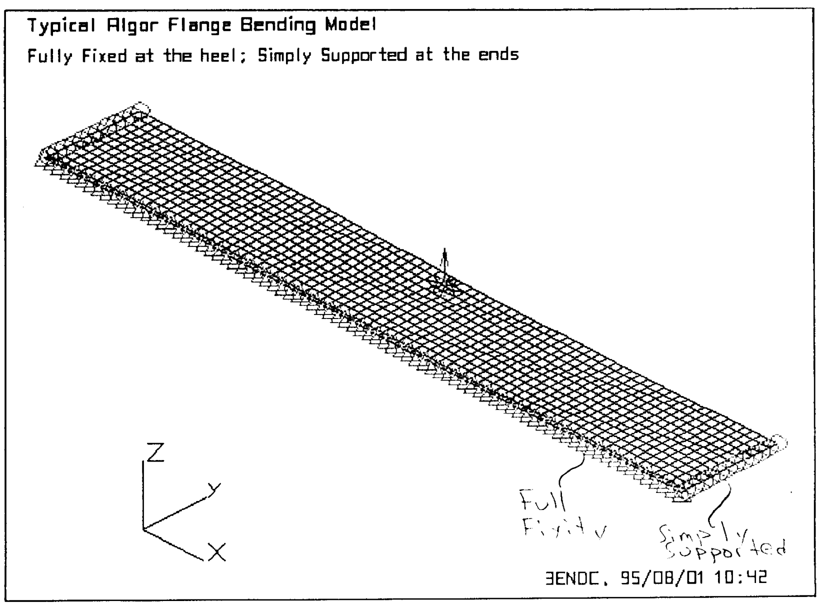
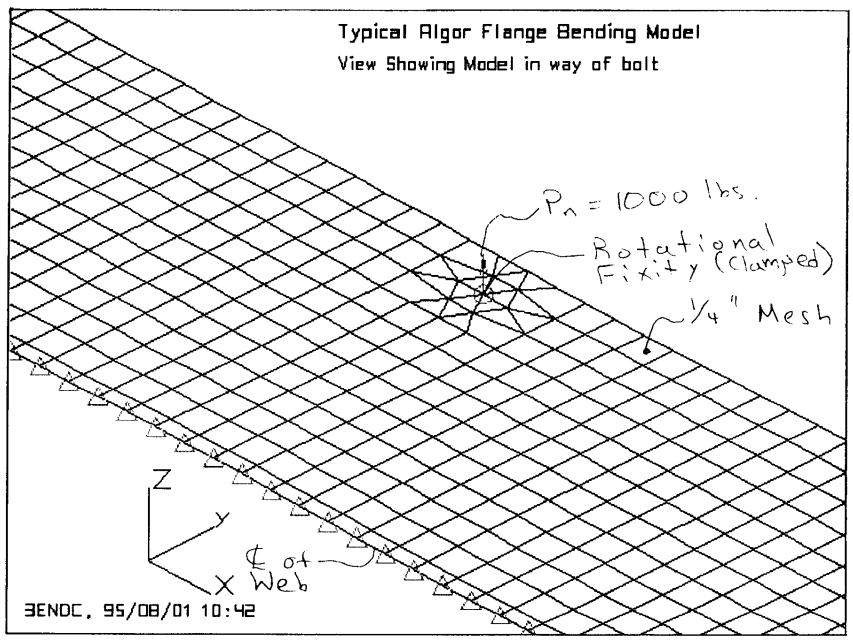


Figure 5-7 — Finite Element Model Details

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 8 OF

Flange Finite Element Model Continued:



Based on this configuration, solve for X:

$$X = \frac{6 \, P_n \, (0.5 \, B - H)}{\sigma \, (\text{from model}) \, F \, t^2}$$

$$= \frac{6 \, (1000 \text{ lbs}) (0.5 (2.5 \text{ in}) - 0.1875 \text{ in})}{\sigma \, (3 \text{ in}) (0.25 \text{ in})^2}$$

$$X = \frac{34{,}000 \text{ psi}}{\sigma \, (\text{from model})}$$

Figure 5-8 — Flange Finite Element Model (Cont'd)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 9 OF

Get Flange Bending Model Stress:

General State of Stress and Deflection:

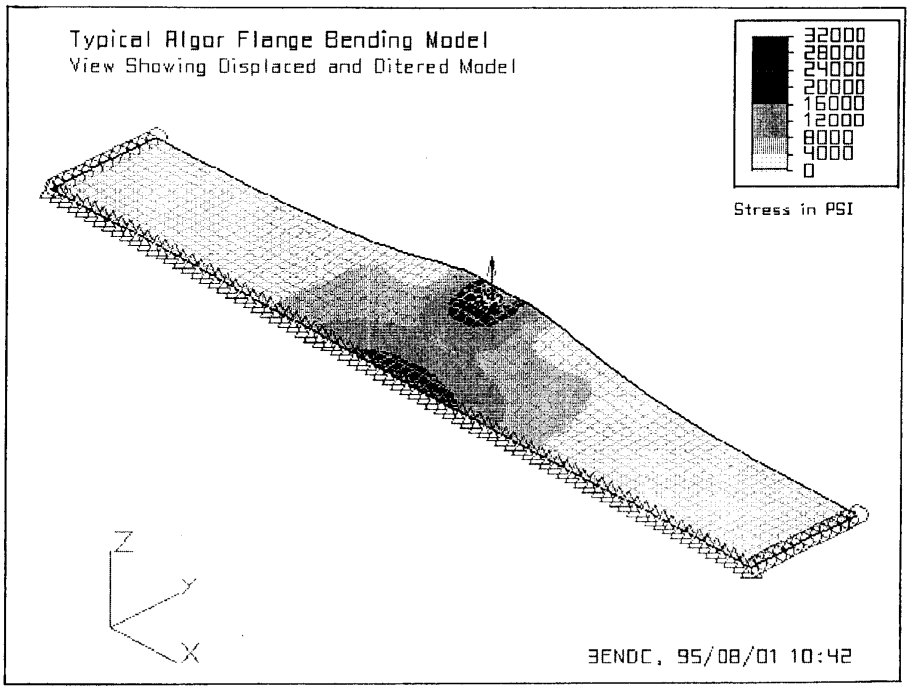
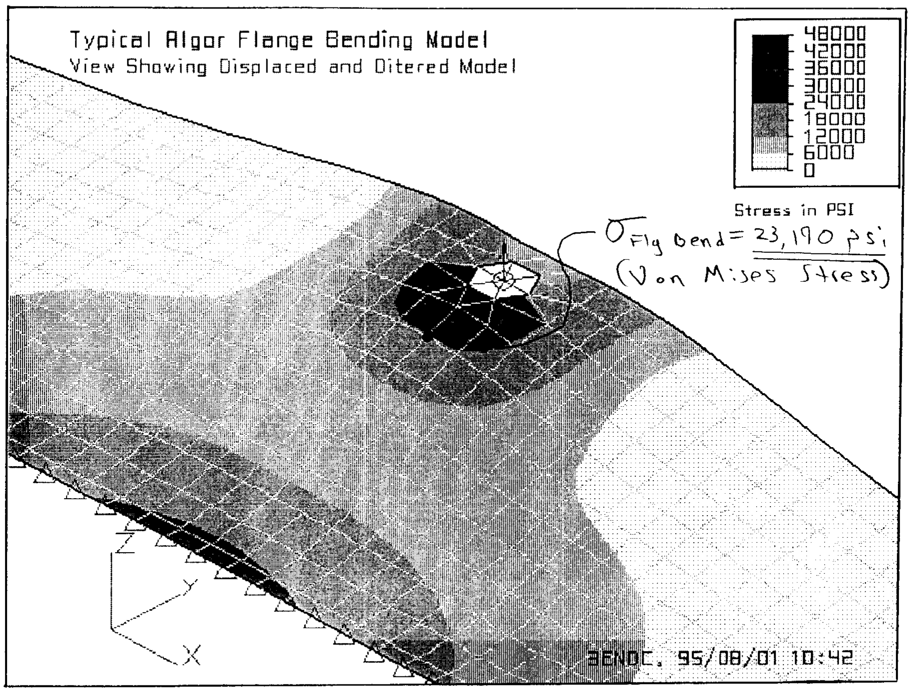


Figure 5-9 — Get Flange Bending Model Stress

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 10 OF

Get Significant Bending Stress:



So,

$$X = \frac{34{,}000 \text{ psi}}{23{,}190 \text{ psi}} = 1.47 \Rightarrow 1.5$$

This same type of model was run for 3 different configurations: 3" Flg w/ the bolt at the flange center; 4" Flg w/ the bolt at the flange end; 4" Flg w/ the bolt at the flange center. The results of all 4 models gives an X of approximately 1.5. This concurs with typical shock flange bending curves.

Figure 5-10 — Get Significant Bending Stress

VIBTECH, INC.

CALCULATION NO. ______

TITLE: ______

CALC. BY | DATE

PROJECT AOE-10, TASK 4 | SHT 11 OF ___

The Flange Bending Formula is Thus:

$$\sigma_{\substack{Flg \\ Bend'g}} = \frac{6 \cdot P_n (A \cdot B - H)}{1.5\ F\ t^2}$$

where,

P_n is the axial bolt force
A is the % of bending moment at the bolt
B is the distance from ℄ web to ℄ bolt
H is half of the bolt head width
F is the flange length
t is the flange thickness

Figure 5-11 — The Flange Bending Formula is Thus

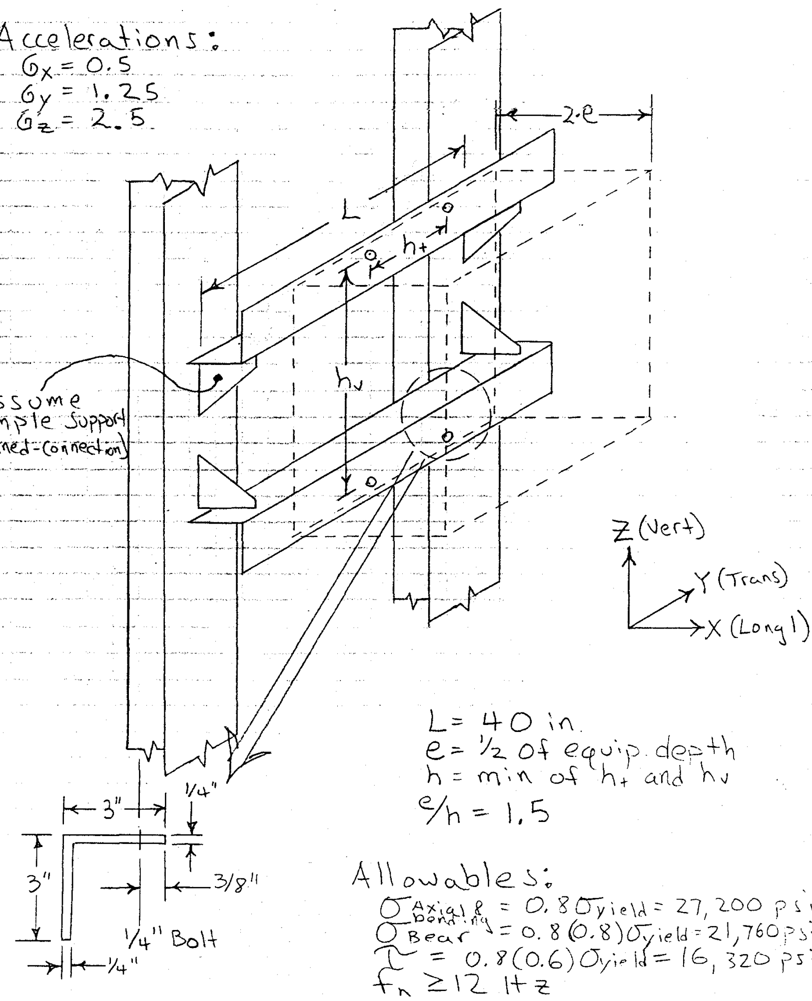
APPENDIX C — GRILLAGE SPREADSHEET CALCULATION METHOD

VIBTECH, INC.	CALCULATION NO.	
TITLE: Grillage Spreadsheet Calculation Method	CALC. BY SLJ	DATE 8/15/95
	PROJECT 95-040	SHT 1 OF 10

Example for Spreadsheet Verification:

Accelerations:

$G_x = 0.5$
$G_y = 1.25$
$G_z = 2.5$



L = 40 in.
e = ½ of equip. depth
h = min of h_t and h_v
$e/h = 1.5$

Allowables:

$\sigma_{Axial\ \&\ bending} = 0.8\,\sigma_{yield} = 27{,}200$ psi
$\sigma_{Bear} = 0.8(0.8)\sigma_{yield} = 21{,}760$ psi
$\tau = 0.8(0.6)\sigma_{yield} = 16{,}320$ psi
$f_n \geq 12$ Hz

Figure 5-1 — Grillage Spreadsheet Calculation Method (Page 1 of 10)

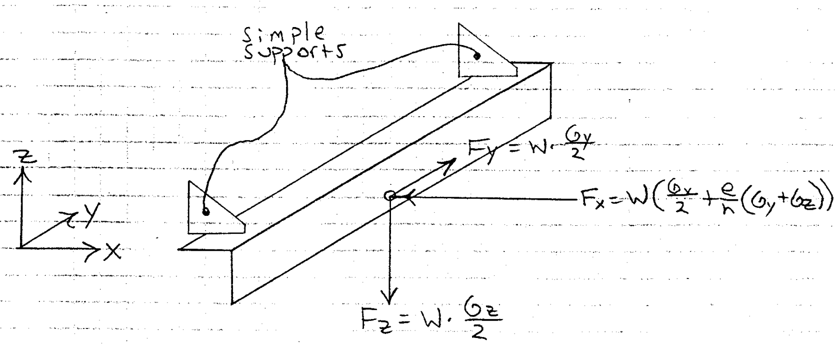
VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 2 OF

Angle Properties:

3" x 3" x 1/4" Angle: $A = 1.4375 \text{ in.}^2$ $Z_{FLG/TOE} = 0.577 \text{ in}^3$
$I_{FLG} = 1.244 \text{ in.}^4$ $Z_{FLG/HEEL} = 1.477 \text{ in}^3$
$I_{web} = 1.244 \text{ in.}^4$ $Z_{web/TOE} = 0.577 \text{ in.}^3$
$Z_{web/heel} = 1.477 \text{ in}^3$

Given these parameters, find the maximum allowable equipment weight.

Resolve forces on angles and bolts:



The calculation resolves forces as if there are 4 bolts, but for the purpose of checking stresses it is assumed that there is one bolt at the center of both angles. This conservative assumption captures all concievable bolting patterns.

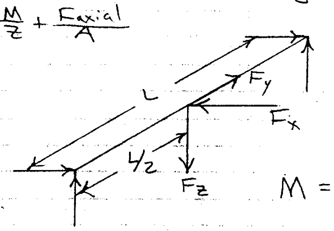
Figure 5-2 — Grillage Spreadsheet Calculation Method (Page 2 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 3 OF

Find allowable weight based on Angle Bending:

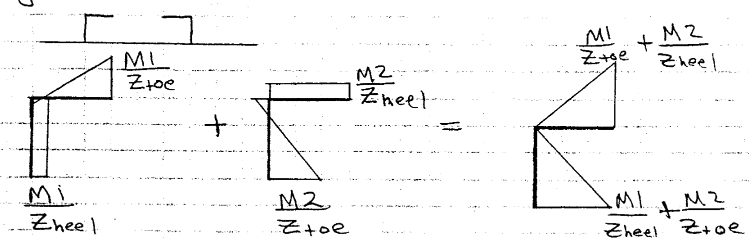
$\sigma = \sigma_{bend} + \sigma_{axial} = \frac{M}{Z} + \frac{F_{axial}}{A}$

2 potential worst locations:
Flg toe &
Web toe



$M = \frac{FL}{4}$

Assume worst double bending situation:
Angles toed in.



$M_z = \frac{FL}{4} = \frac{F_x L}{4} = \frac{W\left(\frac{G_x}{2} + \frac{e}{h}(G_y + G_z)\right)L}{4} = \frac{W\left(\frac{0.5}{2} + 1.5(1.25 + 2.5)\right)(40\,in)}{4}$

$M_z = W(58.75\,in)$

$M_y = \frac{FL}{4} = \frac{F_z L}{4} = \frac{W \cdot \frac{G_z}{2} \cdot L}{4} = \frac{W\left(\frac{2.5}{2}\right)(40\,in)}{4}$

$M_y = W(12.5\,in)$

$\sigma_{web\ toe} = \frac{M_z}{Z_{web\ toe}} = \frac{W(58.75\,in)}{0.577\,in^3} = W\left(101.8\,\frac{1}{in^2}\right)$

$\sigma_{web\ heel} = \frac{M_z}{Z_{web\ heel}} = \frac{W(58.75\,in)}{1.477\,in^3} = W\left(39.78\,\frac{1}{in^2}\right)$

$\sigma_{Flg\ toe} = \frac{M_y}{Z_{Flg\ toe}} = \frac{W(12.5\,in)}{0.577\,in^3} = W\left(21.66\,\frac{1}{in^2}\right)$

$\sigma_{Flg\ heel} = \frac{M_y}{Z_{Flg\ heel}} = \frac{W(12.5\,in)}{1.477\,in^3} = W\left(8.46\,\frac{1}{in^2}\right)$

Figure 5-3 — Grillage Spreadsheet Calculation Method (Page 3 of 10)

VIBTECH, INC.

CALCULATION NO. ______

TITLE: ______

CALC. BY | DATE

PROJECT | SHT 4 OF ___

Find double bending allowables:

$$\sigma^{bend}_{web} = \sigma_{Web\ toe} + \sigma_{Flg\ heel} = W(101.8 \tfrac{1}{in.^2}) + W(8.46 \tfrac{1}{in.^2}) = W(110.26 \tfrac{1}{in.^2})$$

$$\sigma^{bend}_{Flg} = \sigma_{Flg\ Toe} + \sigma_{Web\ heel} = W(21.66 \tfrac{1}{in.^2}) + W(39.78 \tfrac{1}{in.^2}) = W(61.44 \tfrac{1}{in.^2})$$

$\sigma^{bend}_{web} > \sigma^{bend}_{Flg}$, so use σ^{bend}_{web} to figure allowable loads

Find allowable weight based on combined stress:

$$\sigma_{comb} = \sigma^{bend}_{web} + \sigma_{Axial}$$

$$\sigma_{Axial} = \frac{F_{Axial}}{A} = \frac{F_x}{A} = \frac{W \cdot \frac{(24)}{2}}{A} = \frac{W \cdot \frac{1}{2}(1.25)}{1.4375\ in.^2} = W(0.435\ in.^2)$$

$$\sigma_{comb} = W(110.26 \tfrac{1}{in.^2}) + W(0.435\ in.^2) = W(110.7 \tfrac{1}{in.^2})$$

$$\sigma_{comb} \leq \sigma_{Allow}$$
$$\sigma_{comb} \leq 27{,}200\ lbs/in.^2$$

$$W(110.7 \tfrac{1}{in.^2}) \leq 27{,}200\ lbs/in.^2$$

$$\boxed{W \leq 246\ lbs.}$$

Figure 5-4 — Grillage Spreadsheet Calculation Method (Page 4 of 10)

VIBTECH, INC.		CALCULATION NO.
TITLE:	CALC. BY	DATE
	PROJECT	SHT 5 OF

Find allowable weight based on Flange Bending:

$$\sigma = \frac{P(0.8B-H)}{1/4\, t^2 F}$$ ~ See Appendix B for derivation of this formula

where,

P = force on bolt $= F_x = W\left(\frac{G_x}{2} + \frac{e}{h}(G_y + G_z)\right)$

B = dist from ℄ bolt to ℄ web $= 3\text{in} - 0.375\text{in} - \frac{0.25\text{in}}{2} = 2.5\text{in}$

H = ½ dia. of the bolt head = 0.21875 in for ¼" bolt

t = flange thickness = 0.25 in

F = flange length

$$\sigma = \frac{W\left(\frac{G_x}{2} + \frac{e}{h}(G_y+G_z)\right)(0.8(2.5\text{in}) - 0.21875\text{in})}{1/4\,(0.25\text{in})^2(3\text{in})}$$

$$= \frac{W\left(\frac{0.5}{2} + (1.5)(1.25+2.5)\right)(0.8(2.5\text{in}) - 0.21875\text{in})}{1/4\,(0.25\text{in})^2(3\text{in})}$$

$$\sigma = W\left(223.25\ \frac{1}{\text{in}^2}\right)$$

$\sigma \le \sigma_{Allow}$

$\sigma \le 27{,}200\ \text{lbs/in}^2$

$$W\left(223.25\frac{1}{\text{in}^2}\right) \le 27{,}200\ \text{lbs/in}^2$$

$$\boxed{W \le 122\ \text{lbs.}}$$

Figure 5-5 — Grillage Spreadsheet Calculation Method (Page 5 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 6 OF

Find allowable weight based on Bolt Pull-Thru:

$$\tau = \frac{P}{1.5\, d\, \pi\, t}$$

where,

P = force on bolt $= F_x = W\left(\frac{G_x}{2} + \frac{e}{h}(G_y + G_z)\right)$

d = bolt nominal diameter = 0.25 in.

t = angle thickness = 0.25 in.

$$\tau = \frac{W\left(\frac{G_x}{2} + \frac{e}{h}(G_y + G_z)\right)}{1.5\,(0.25\,in)\,\pi\,(0.25\,in)}$$

$$= \frac{W\left(\frac{0.5}{2} + (1.5)(1.25 + 2.5)\right)}{1.5\,(0.25\,in)\,\pi\,(0.25)}$$

$$\tau = W\left(19.95\,\frac{1}{in^2}\right)$$

$$\tau \leq \tau_{ALLOW}$$

$$\tau \leq 16{,}320\ lbs/in^2$$

$$W\left(19.95\,\frac{1}{in^2}\right) \leq 16{,}320\ lbs/in^2$$

$$\boxed{W \leq 818\ lbs.}$$

Figure 5-6 — Grillage Spreadsheet Calculation Method (Page 6 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 7 OF

Find allowable weight based on Bolt Tear-Out:

$$\tau = \frac{P_P}{2(D-0.32d)t}$$

where,

P_P = shear force on bolt = $F_z = W \cdot \frac{G_z}{2}$

D = dist. from ℄ bolt to flg toe = 0.375 in.

d = nominal bolt diameter = 0.25 in.

t = flange thickness = 0.25 in.

$$\tau = \frac{W \cdot \frac{G_z}{2}}{2(0.375\,in - 0.32(0.25\,in))(0.25\,in)}$$

$$= \frac{W \cdot \frac{2.5}{2}}{2(0.375\,in - 0.32(0.25\,in))(0.25\,in)}$$

$$\tau = W\left(8.475 \tfrac{1}{in^2}\right)$$

$$\tau \leq \tau_{ALLOW}$$

$$\tau \leq 16{,}320\ lbs/in^2$$

$$W\left(8.475 \tfrac{1}{in^2}\right) \leq 16{,}320\ lbs/in^2$$

$$\boxed{W \leq 1926\ lbs}$$

Figure 5-7 — Grillage Spreadsheet Calculation Method (Page 7 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 8 OF

Find allowable weight based on Bolt Bearing:

$$\sigma_{Bear} = \frac{P_p}{d \cdot t}$$

Where

P_p = Shear force on bolt $= F_z = W \cdot \frac{G_z}{2}$

d = nominal bolt diameter = 0.25 in

t = flange thickness = 0.25 in.

$$\sigma_{Bear} = \frac{W \cdot \frac{G_z}{2}}{(0.25\,in)(0.25\,in)}$$

$$= \frac{W \cdot \frac{2.5}{2}}{(0.25\,in)(0.25\,in)}$$

$$\sigma_{Bear} = W\left(20 \frac{1}{in^2}\right)$$

$$\sigma_{Bear} \leq \sigma_{Bear\ allow}$$

$$\sigma_{Bear} \leq 21{,}760\ lbs/in^2$$

$$W\left(20 \frac{1}{in^2}\right) \leq 21{,}760\ lbs/in^2$$

$$\boxed{W \leq 1088\ lbs}$$

Figure 5-8 — Grillage Spreadsheet Calculation Method (Page 8 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 9 OF

Find allowable weight based on Fdn. Natural Frequency:

$$f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Check vibration perpendicular to the plane of the foundation.

$$\frac{1}{K_{Ang\ Perp}} = \frac{1}{K_{Ang\ Bend}} + \frac{1}{K_{Flg\ Bend}} + \frac{1}{K_{Ang\ Torsion}}$$

But, if it assumed that the equipment is clamped at the bolt, which produces the worst case for flange bending, then torsional rotation does not occur, because it is resisted by the moment produced by the clamping at the bolt. So,

$$\frac{1}{K_{Ang\ Perp}} = \frac{1}{K_{Ang\ Bend}} + \frac{1}{K_{Flg\ Bend}}$$

$$K_{Ang\ Bend} = \frac{48EI}{L^3} = \frac{48(30\times10^6\ lbs/in^2)(1.244\ in^4)}{(40\ in)^3} = 27{,}990\ \frac{lbs}{in}$$

$$K_{Flg\ Bend} = \frac{1.6\times10^7\ t^3}{B^2}\cdot k'$$

B = dist. from ℄ bolt to ang. heel = 2.5 in.

K' = factor for flange case (see App.) = 1.5 in.

$$K_{Flg\ Bend} = \frac{1.6\times10^7(0.25\ in)^3}{(2.5\ in)^2}(1.5) = 60{,}000\ lbs/in.$$

$$\frac{1}{K_{Ang\ Perp}} = \frac{1}{27{,}990\ lbs/in} + \frac{1}{60{,}000\ lbs/in} = 5.24\times10^{-5}\ in/lbs$$

$$K_{Ang\ Perp} = \frac{1}{5.24\times10^{-5}\ in/lbs} = 19{,}086\ lbs/in.$$

$$K_{Perp} = 2_{Angs}\cdot K_{Ang\ Perp} = 2(19{,}086\ lbs/in) = 38{,}172\ lbs/in.$$

Compare this stiffness to other modes of vibration. The lowest K will produce the lowest fn and thus the least allowable weight.

Figure 5-9 — Grillage Spreadsheet Calculation Method (Page 9 of 10)

Figure 5-10 — Grillage Spreadsheet Calculation Method (Page 10 of 10)

VIBTECH, INC.	CALCULATION NO.	
TITLE:	CALC. BY	DATE
	PROJECT	SHT 10 OF

Allowable weight based on Natural Frequency (continued):

Check vibration parallel to the plane of the fdn.

$K_{parallel} = 2 \cdot K_{\substack{Ang\\Bend}} = 2(27{,}990 \text{ lbs/in}) = 55{,}980 \text{ lbs/in.}$

Check vibration of equipment overturning:

$$\frac{1}{K_{over}} = \frac{1}{0.5\left(\frac{1}{e/h}\right)^2 \cdot K_{\substack{Ang\\perp}}} + \frac{1}{2 \cdot K_{\substack{Ang\\Bend}}}$$

$$\frac{1}{K_{over}} = \frac{1}{0.5\left(\frac{1}{1.5}\right)^2 (19{,}086 \text{ lbs/in})} + \frac{1}{2(27{,}990 \text{ lbs/in})} = 2.54 \times 10^{-4} \frac{\text{in.}}{\text{lbs.}}$$

$K_{over} = 3{,}943 \text{ lbs/in.}$

Calculate allowable weight based on lowest K

$K = \text{Min of } K_{perp}, K_{parallel} \ \& \ K_{over} = K_{over} = 3{,}943 \text{ lbs/in}$

$$f_n = 12 \text{ Hz} = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$$

$$m_{allow} = \frac{K}{(12 \text{ Hz} \cdot 2\pi)^2} = \frac{(3{,}943 \text{ lbs/in})(386 \text{ in/sec}^2)}{(12 \text{ Hz} \cdot 2\pi)^2}$$

$m_{allow} = 268 \text{ lbs.}$

$\boxed{W \leq 268 \text{ lbs}}$

Thus, the allowable weight based on flange bending is:

$\boxed{W \leq 122 \text{ lbs}}$

APPENDIX D — BEND TEST REPORT OF 12” AND 18” PIPE HANGER PROTOTYPES WITH 3/4” AND 1” DIAMETER WELD STUDS

THE TEST

The following bend tests were performed on 12” and 18” long prototype pipe hanger designs. The weld studs tested were the NASSCO 3/4” × 3-1/16” XBL Square Stud #101-111-090 and a prototype 1”×4-1/4” press formed weld stud.

BEND TEST FIXTURE

The studs were welded to 4”×4”×5/8” thick mild steel plates with 4 each 0.540 diameter holes. The plates were then mounted to a 2”×10”×24” plate fixture with 4 each 1/2”×4” grade 2 bolts. Assemblies were clamped and braced under the compression test equipment before each test. Pipe hangers were attached to the studs with 2 each 3/8” grade 2 bolts.

TEST OBSERVATIONS AND COMMENTS

TEST NO. 1

At approximately 325 lbs., the 3/4” stud started to yield at about 0.400” deflection. Total load at 1.500” deflection was 405 lbs. The pipe hanger did not yield.

TEST NO. 2

At approximately 160 lbs., the 3/4” stud started to yield at about 0.600” deflection. Total hanger deflection after load was released was about 0.250”.

TEST NOS. 3 AND 4

The 1” diameter weld stud did not bend. Maximum load was achieved at about 1.500” deflection in both tests.

TEST NO. 5

Significant additional strength was obtained with the addition of a side brace. Over 500 lbs. Was applied before measuring 0.100” of deflection. The 3/4” diameter weld stud did not yield. A 1/2”×1” CFL mild steel weld stud was used to fasten the “L” bracket to the test plate. The threaded stud was located 16” on center from the center of the hanger.

TEST NO. 6

The 1” diameter stud did not yield. Higher load values could be obtained with modification to the clamp around the top at the hanger to keep it from sliding. Similar load values would be expected from a 3/4” diameter weld stud. A 1/2”×1 CFL mild steel weld stud was used to fasten the “L” bracket to the test plate. The threaded stud was located 12” on center from the center of the hanger.

TEST NO. 7

The goal post was connected at the top with a 3/8”×3”×18” steel plate with two 5/8”×2” bolts. Both weld studs started to yield at about 1150 lbs. with 0.600” deflection.

TEST NO. 8

The goal post was connected at the top with a 3/8”×3”×18” steel plate with two 5/8”×2” bolts. The 1” diameter weld studs did not yield.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 6 — MANUFACTURING AND INSTALLATION TECHNIQUES

PRINCIPAL INVESTIGATOR:

DOMINIC BURNS
SENIOR ENGINEER
NATIONAL STEEL AND SHIPBUILDING COMPANY

ADDITIONAL INVESTIGATOR:

JOHN HOPKINSON
PRESIDENT
VIBTECH, INC.

UNIVERSITY OF NEW ORLEANS
NEW ORLEANS, LA 70148

TABLE OF CONTENTS

APPENDICES

6 MANUFACTURING AND INSTALLATION TECHNIQUES

OVERVIEW

This section investigated the candidate attachment techniques and manufacturing processes that would significantly reduce manufacturing and installation time. Significant savings are possible for H, M & E equipment and system installations by shifting manufacturing work to the shop and by designing the ship systems for easy installation during ship assembly. The combination of these two factors will greatly reduce the overall time of construction from keel laying to ship delivery.

Current shipbuilding practice is governed by obsolete and inefficient technologies that result in a disproportionately large amount of labor man-hours being spent aboard the ship assemblies and erection units rather than in the more efficient shop environment. It is generally recognized that shop work is more efficient than shipboard work. Modular construction is touted as a modern technique for reducing ship construction costs. While hull structure costs have been somewhat reduced by modular construction techniques, labor hours required to outfit the subassemblies and erection units remain very high. Accordingly, the installation man hours of H,M&E equipment and distributive systems aboard subassemblies, assemblies and erection units is approximately ten (10) times the man hours spent in the shop.

The technologies, materials, devices, methods, processes and techniques used today for the installation of individual or combined systems or equipments are based on old-fashioned ship design approaches. The typical approach used in shipyards responsible for the design and construction of our modern US surface combatants and commercial ships is to use technologies, methods, processes and standards from previous ship designs. Designers are instructed by in house office procedures to use examples from previous designs as guidance for new designs. The US surface combatant/commercial shipbuilding community is reluctant to change because the practice appears to work and the status quo is maintained. While some change has occurred, the process is evolutionary rather than revolutionary. In order to make US surface ships more affordable, a radical change in the technologies to install H, M&E equipment and systems is necessary. The “devil is in the details,” thus revolutionary changes in the technologies, materials, devices, methods, processes and techniques used to install H, M&E equipments and systems are necessary if we are to make US combatants and commercial ships more affordable.

APPROACH

In order to achieve these dramatic cost savings to make US surface ships more affordable, an effective strategy to revolutionize HM&E technologies must be developed in order to change the design and construction practices for US Navy surface ships. These important strategies are offered for review:

1. Identify revolutionary technologies for installing H, M & E individual or combined systems or equipments that will substantially reduce both the time and cost for the overall design, construction and delivery of ships;

2. Explore development of revolutionary techniques, methods and standards that will significantly reduce on-block H, M & E individual or combined systems or equipment installation time and costs by shifting work from the ship to the shop;

3. Explore development of revolutionary technologies that will accelerate ship construction with a dynamic build and outfit strategy to radically reduce the keel laying to ship delivery time.

4. Perform exploratory investigations to include analytical and experimental development of the revolutionary H, M & E outfit installation techniques, methods and standards to include strength, fatigue and dynamic loading assessments to satisfy both commercial vessels and U.S. Navy performance requirements.

5. Develop guidance and standards for rapid installation of individual or combined systems or equipments.

These strategies are essential to conducting an exploratory development of HM&E technologies that can revolutionize US Navy surface ship design and construction to provide more affordable ships. Important considerations in carrying out these considerations are outlined as follows:

TECHNOLOGIES TO INSTALL SYSTEMS AND OUTFIT TO REDUCE TIME AND COSTS

The cost of H, M & E equipment, outfit and distributive system installations, i.e., piping, electrical and HVAC systems is extremely high per ton in comparison to the cost of fabrication and erection of basic hull steel, because engineering and design procedures as well as fabrication and installation procedures are labor intensive. The present technology for installing H, M & E equipment foundations, equipment and distributive systems affects the time required to complete on-block assembly, therefore the technology affects the critical path for ship construction. There has been little effort expended to reduce the labor and high cost of foundations, their installation and H, M & E system installations.

The development of new and innovative standards for H, M & E foundations and systems installations can reduce the cost of their manufacture and can significantly reduce the time required for installation that is on the critical path for overall ship construction. Reduction in on-block assembly time would reduce the overall construction time from keel laying to delivery. Cost and time parameters that can be affected by standards development include:

- Design and engineering labor,
- Manufacturing labor, for H, M & E systems installations,
- Shipyard handling labor and overhead,
- Installation of H, M & E equipment and systems labor,
- Reduction in sub-assembly construction time,
- More rapid ship assembly to reduce ship delivery time.

The use of new and innovative standards for HM&E equipment and system installations will significantly improve productivity, quality and customer satisfaction and will reduce the cost and overall construction time for ships. These standards developed to suit the performance requirements for U.S. Navy vessels will substantially reduce their acquisition cost and will enable earlier delivery of the vessels.

TECHNOLOGIES TO REDUCE ON-BLOCK CONSTRUCTION TIME BY SHIFTING WORK FROM THE SHIP TO THE SHOP

New techniques, methods and standards for installing H, M & E equipment and systems can revolutionize ship assembly practice to achieve significant reduction in on-block construction time by shifting work performed from the ship to the shop.

Ship hull construction employing modular assembly and erection techniques has altered ship construction practice and has achieved significant cost savings compared to old fashioned techniques used when ship hulls were constructed piece by piece on the building ways. However, the traditional techniques and methods to outfit ships, i.e., fabrication of foundations, installation of equipment, and both the fabrication and installation of distributive systems and outfit items, have not been substantially improved to reduce the cost of ships. An extraordinary amount of time, perhaps as much as 10 to 1, is spent by labor aboard ship, (on-block assembly) rather than in the shop. Additional time spent in the shop manufacturing improved techniques, methods and standards to facilitate installation of H, M & E equipment, systems and outfit aboard ship will significantly reduce on-block labor.

The old fashioned techniques employed for outfitting on-block are reflected in long construction times and greater shipyard man-hours for both direct and indirect labor and other time dependent costs of construction. The non value-added labor

for designing custom parts, material take-off, handling, storing, tracking, retrieving and transporting parts to the job site aboard ship, tacking, welding, cleaning and painting of parts are not normally reflected in the current job cost accounting that is traceable to the part, thus it is difficult to quantify alternative methods in terms of shipbuilding time and cost reduction.

New techniques, methods and standards that will permit shifting on-block H, M & E work from the ship to the shop will result in a significant reduction of on-block time and costs while increasing shop work a small amount in comparison. The development of standard techniques, and methods for installation also will reduce costs for fabrication of H, M & E system components.

TECHNOLOGIES THAT WILL ACCELERATE SHIP CONSTRUCTION WITH A RAPID OUTFIT AND BUILD STRATEGY

New technologies for materials, fabrication techniques and standard designs for equipment and systems that permit easy and fast installation of H, M & E equipment and systems will revolutionize and accelerate the ship assembly process. New techniques for H, M & E foundations and system installations will permit easy and rapid attachment of both large and small equipments (pumps, motors, controllers, etc.) and piping, cabling and HVAC systems, etc. to the ship hull structure with minimum labor content. The installation process will be more analogous to the automobile assembly process using quick mechanical installations rather than the heavy and time consuming welding processes used presently to install foundations and systems. The “Family of Foundations” illustration, shows foundation designs that have been developed to facilitate simplified attachment methods.

FAMILY OF FOUNDATIONS

The development of revolutionary standards for H, M & E equipment and systems installations that will permit rapid modular assembly will facilitate the construction of the hull modules by reducing the labor time and cost in both the “Hot” pre-outfit and “Cold” outfit phases of construction. This exploratory research and development effort will focus on the development of techniques, methods and standards that will facilitate the shifting of H, M & E outfit of foundations and systems installations from the labor intensive “Hot” pre-outfit construction practice to the considerably more efficient “Cold” outfit assembly line practice. See Figure 6-1.

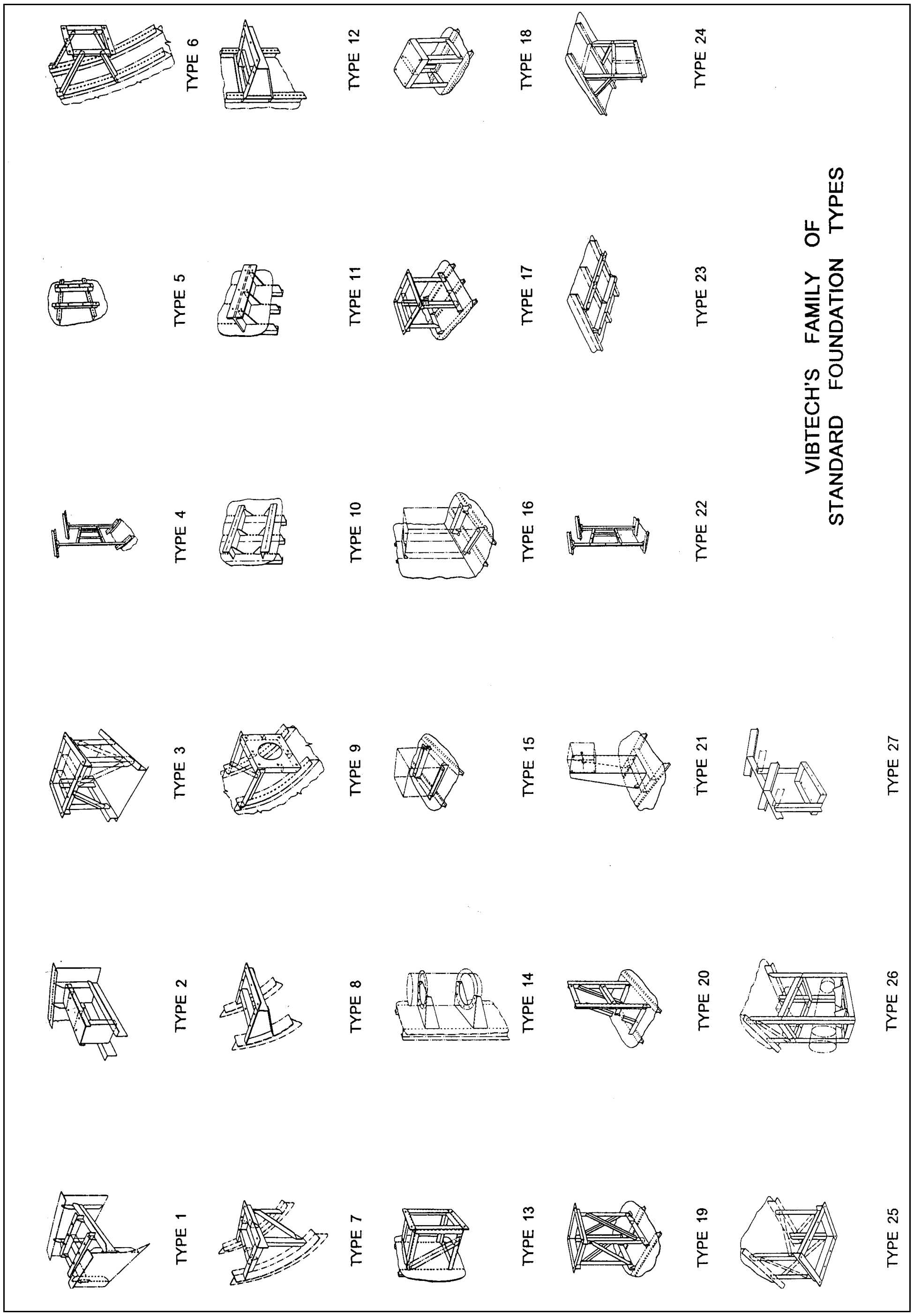


Figure 6-1 — Family of Foundations

The new techniques, methods and standards developed to suit both shop work and simplified outfit will integrate nicely with Simulation Based Design (SBD) and concurrent engineering to reduce overall engineering design time. The development of H, M&E systems installations to support a more competitive build strategy using the revolutionary H, M&E standards will achieve significant reduction in ship construction time and costs.

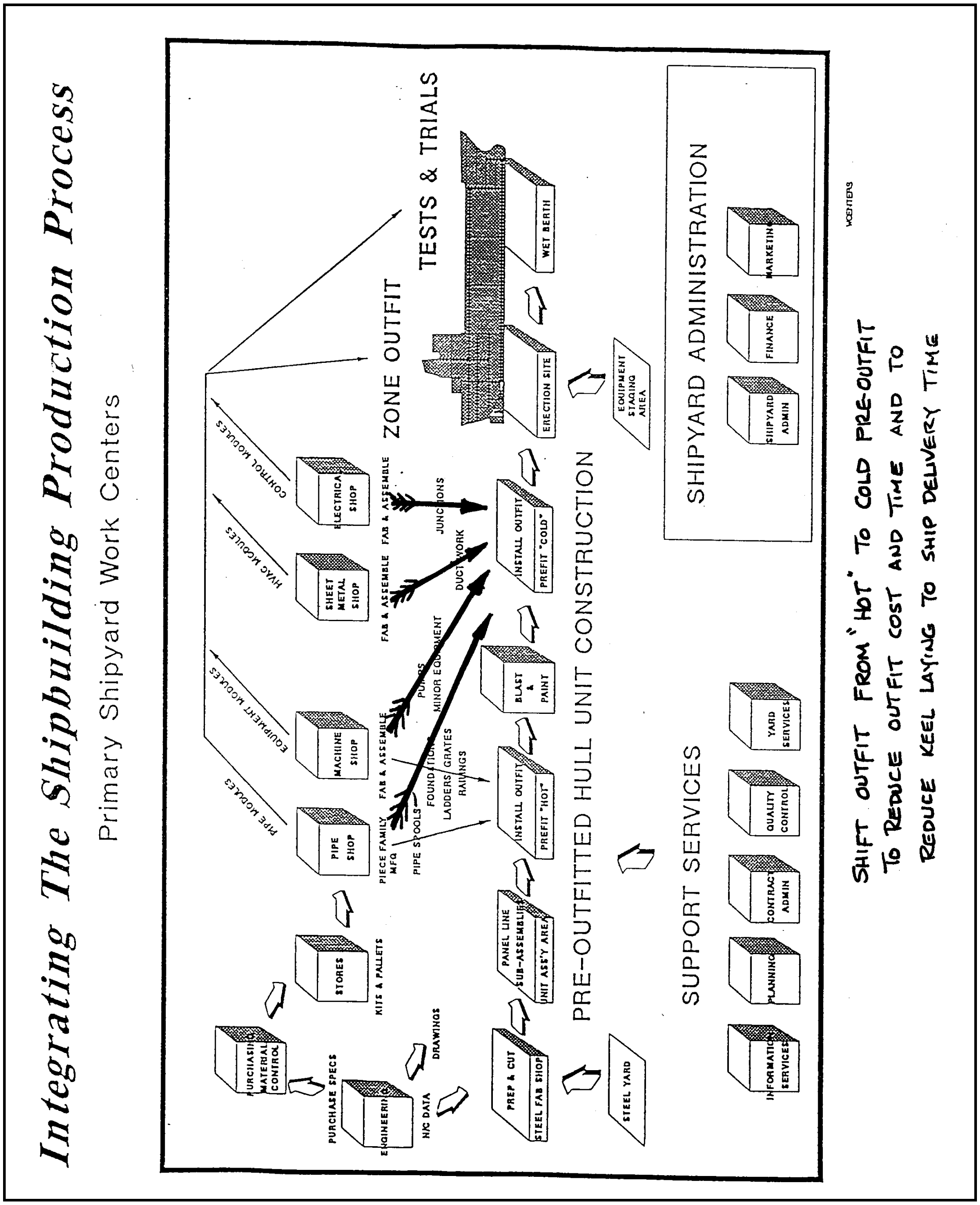


Figure 6-2 — Shipbuilding Production Process

ANALYTICAL AND EXPERIMENTAL INVESTIGATIONS REQUIRED TO VALIDATE RAPID H, M&E OUTFIT AND BUILD STRATEGY

In order to provide more affordable ships through the development of revolutionary HM&E technology concepts, it is essential to perform research and development of these revolutionary concepts and their arrangements in order to establish their validity and acceptability for use in both U.S. Navy and commercial applications. It is proposed that appropriate strength, fatigue, shock, noise and vibration investigations be made to identify all performance requirements, analysis be made and experimental testing be conducted on a selected set of representative H, M & E equipments and distributive system installations to validate the performance capability of new revolutionary techniques, methods and standards proven to be cost effective. It is anticipated that this effort will demonstrate the validity of the development of new H, M & E revolutionary concepts for outfit and build strategy and will result in a revolutionary approach to ship design and construction that will achieve the affordability goals of this solicitation, the U.S. Navy and commercial interests.

GUIDANCE AND STANDARDS FOR RAPID OUTFIT AND BUILD STRATEGY

These investigations should result in the development of guidance and standards to support design development and construction for both US Navy surface ships and commercial vessels. These new techniques, methods and standards will facilitate a new outfit strategy that will permit shifting of labor intensive and high cost work performed in the ship to a more efficient work environment in the shop. This new technology will also permit the development of a change in the build strategy for ships that will reduce the time required to outfit ships in both the “Hot” pre-outfit stage and the “Cold” outfit stage of construction.

ADAPT MECHANICAL CONNECTIONS TO FACILITATE OUTFITTING STRATEGIES

The approach we have taken is to develop candidate details to install Hull, Mechanical, and Electrical system components for individual and/or combined systems and equipments. See Figure 6-2 for candidate equipment installation detail concepts.

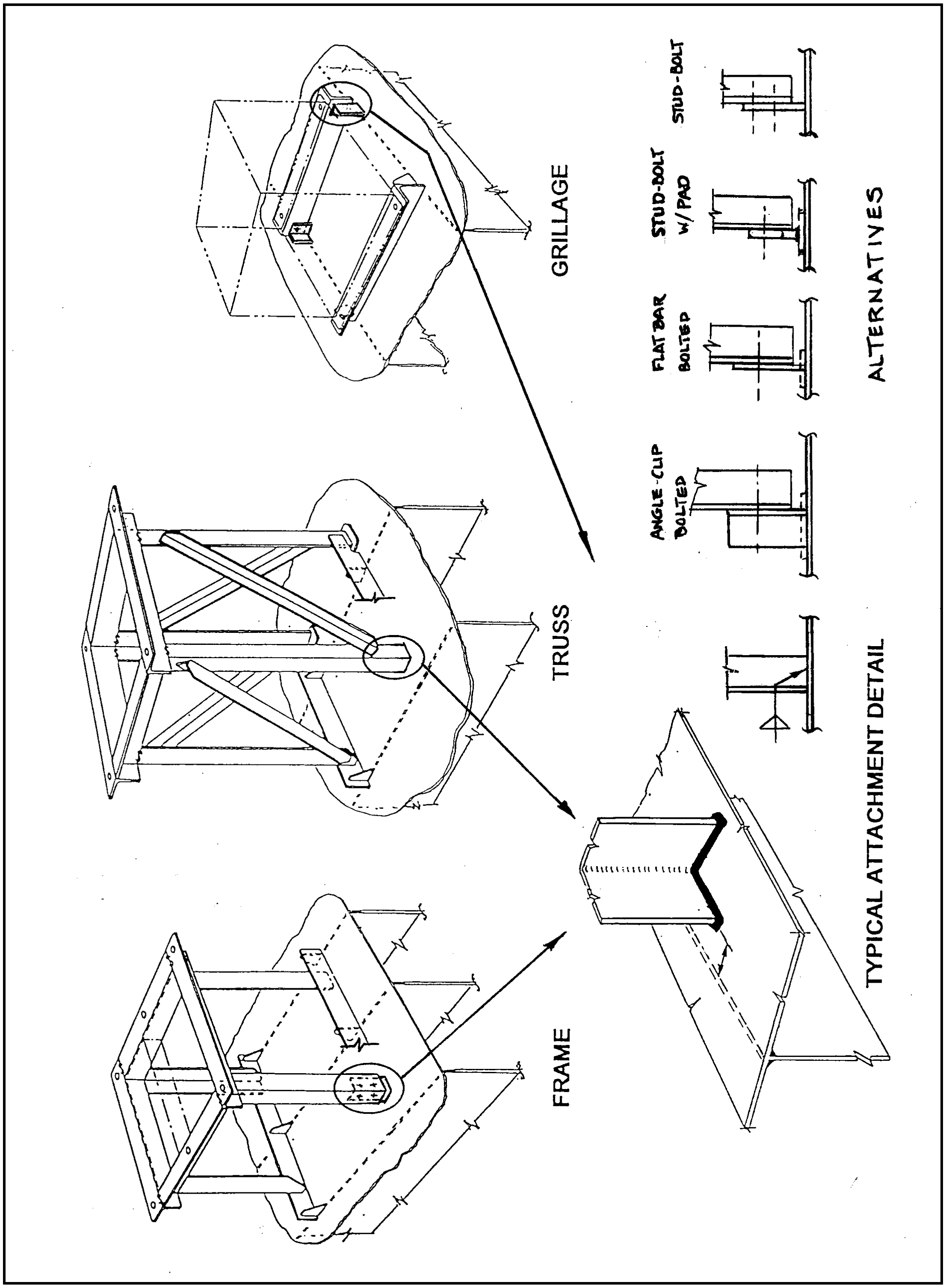


Figure 6-1 — Typical Attachment Detail Alternatives

DEVELOP MECHANICAL SYSTEM ATTACHMENT FOR SPACE FRAME LATTICE AND OTHER SYSTEM OUTFIT PACKAGING TECHNIQUES

We have developed an approachto outfitting methods using panels, gridwork, space-frame lattice works, packages and outfit modules to support an advanced outfitting strategy using mechanical attachment techniques. These methods and techniques should facilitate blast and paint, fitting insulation and final installation of individual or combined system and/or equipment installations. See Figure 6-3.

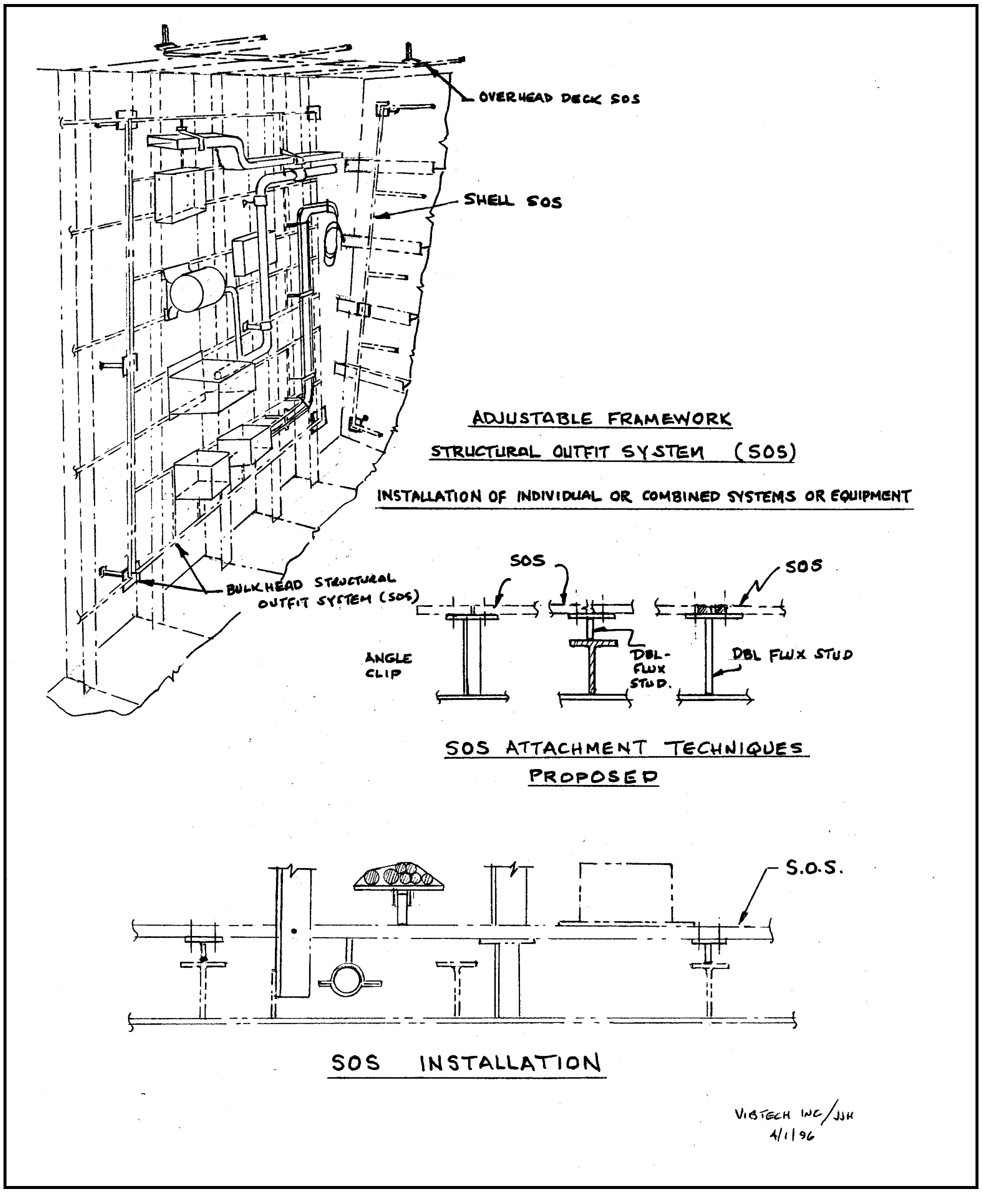


Figure 6-1 — Lattice System Installation Concepts

PIPING SYSTEM INSTALLATIONS

We have developed alternates to traditional all-welded piping systems to facilitate blast and paint, fitting insulation and final installation of piping systems. See Figure 6-4 for candidate piping system installation detail concepts.

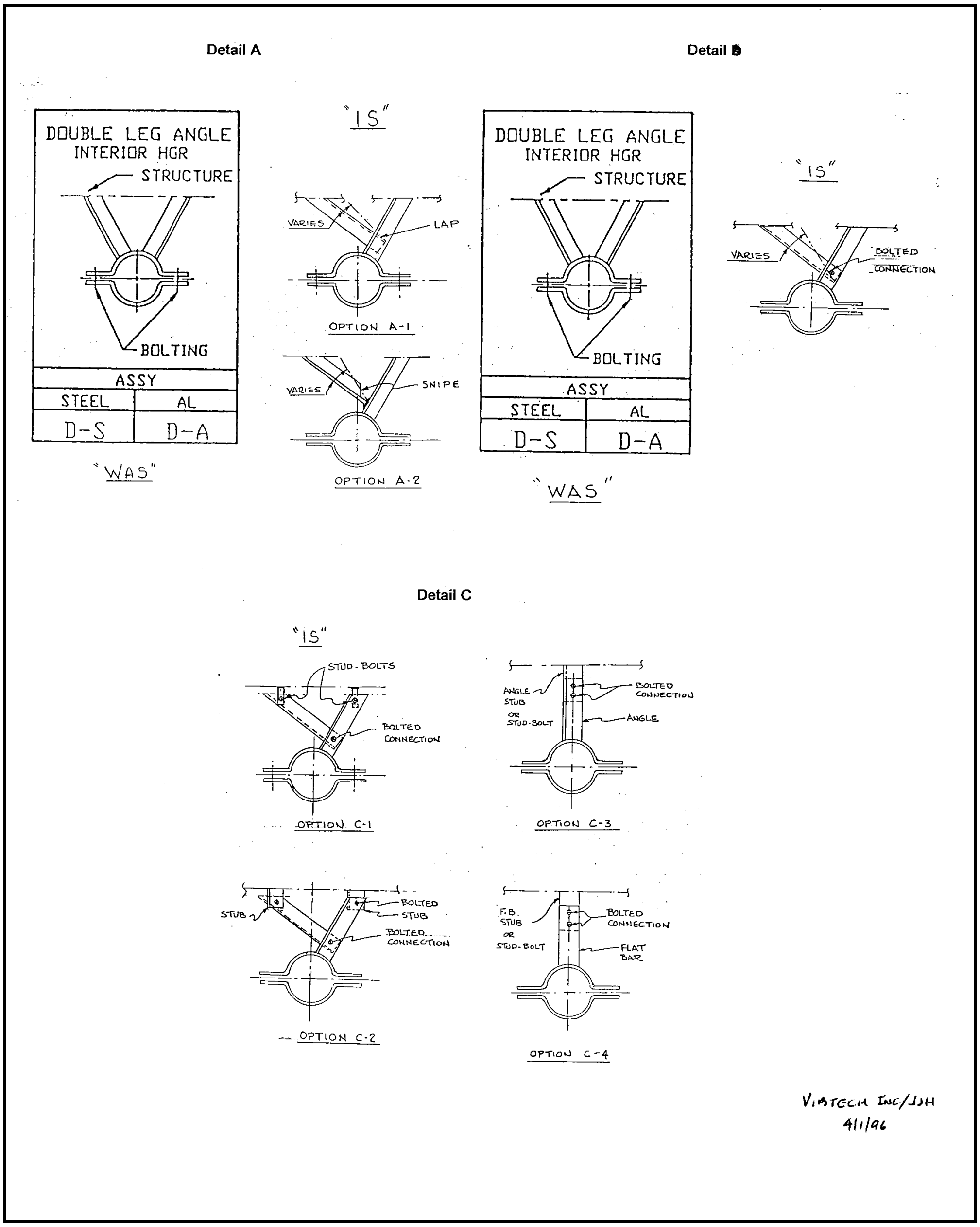


Figure 6-1 — Pipe Hanger Design Alternates

Vibtech Inc. believes that, with a proper mathematical characterization of piping system and hangers and the use of high strength materials, significant economies in hanger design, See Figure 6-4, can be achieved as follows:

1. Unnecessary backup structure and pads in way of hangers can be eliminated.

2. Sway Braces or lateral support for small diameter pipe can be removed, i.e. '/," IPS through 3**/,'** [PS. (DDG-51 quantity = 920)

3. Type D hangers may not be required for 1" IPS through 2" IPS pipe sizes for stand-off lengths up to 24 inches. Type C hangers may be used in lieu of Type D

4. Hangers Scantlings can be reduced and greater standardization can be achieved; clamp thickness can be reduced and significant weight savings can be achieved.

5. Manufacturing simplification can be achieved for Type D hangers. A single downcomer leg may be welded to the clamp and the sway brace lap welded to the downcomer at the proper angle. (See Detail A)

6. Installation simplification can be achieved by developing design standards using bolted attachments of the sway brace to the clamp downcomer, (Type D). (See-Detail B)

7. Mechanical attachments can be developed for all hanger systems to facilitate blast and paint, fitting insulation and final installation of piping systems with hangers in PO-2 to improve the hot pre-outfit (PO-1) schedule, blast and paint schedule and pre-outfit (PO-2) schedule. Final installation of pipes and hangers can be shifted to the cold pre-outfit stage of construction. (PO-2). The procedure will permit outside/shop manufacture of pipe hangers with final paint/preservation of the hangers before installation of piping and hangers. (See Detail C)

ELECTRICAL SYSTEM INSTALLATIONS

Alternatives have been developed to electrical system installations to facilitate blast and paint, fitting insulation and final installation of cableways and cable. See Figure 6-5 for alternative methods for supporting the cableways.

STUD MOUNTING PLATE METHODS

Bolt studs and alternative methods can be used to mount equipment and systems. These range from stud-bolts that can be manufactured in various length to facilitate standards development for both pipe and cable hangers, See Figure 6-5, through to double flux type studs that can expedite the attachment of equipment and outfit, See Figure 6-6.

SMART SYSTEMS (SHIPBOARD MODULAR ARRANGEMENT RECONFIGURATION TECHNOLOGY)

The SMART system uses a modular track system with an attachment assembly to install systems and components. A description of the system is included within this section.

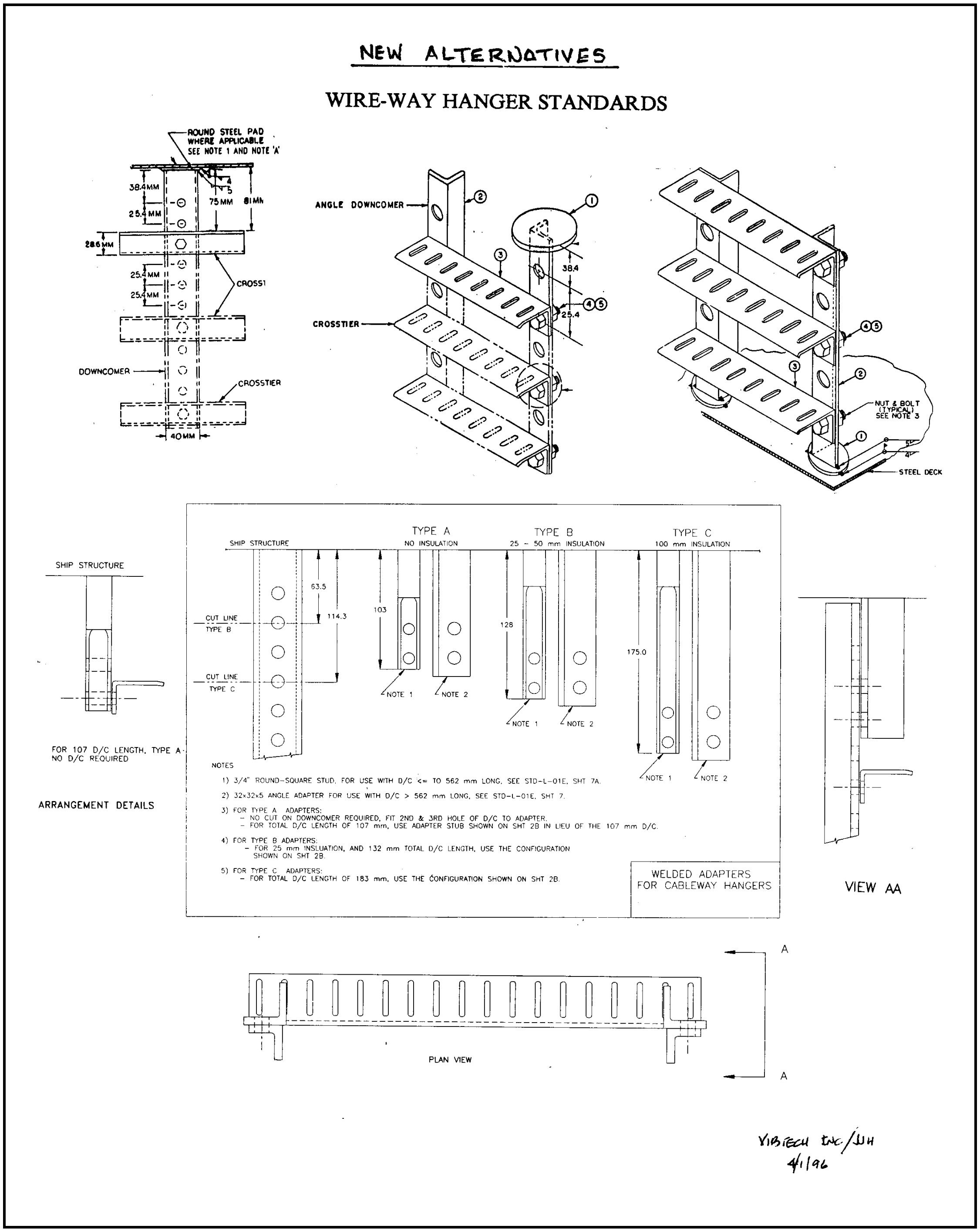
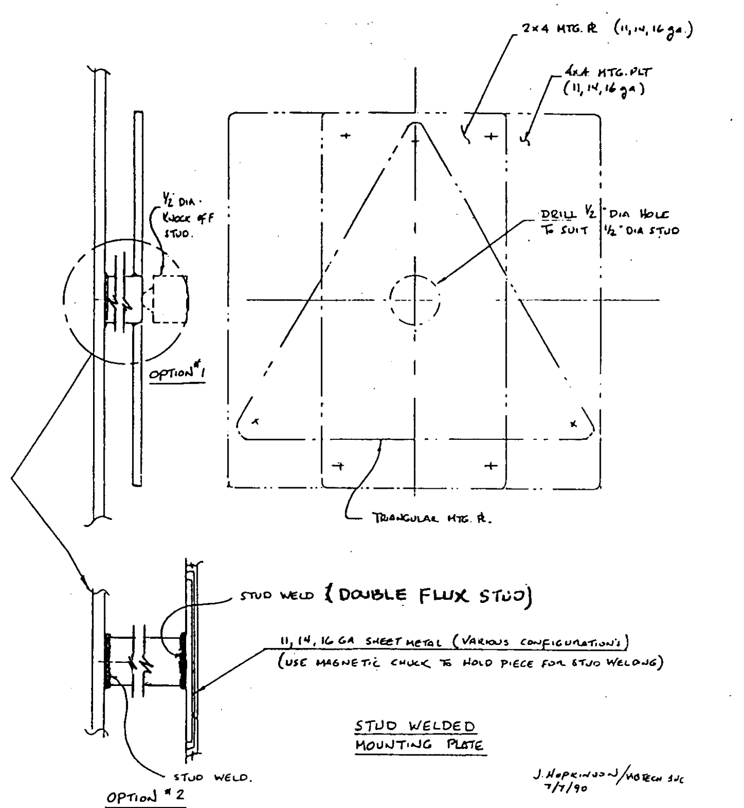


Figure 6-1 — Cable Way Hanger Attachments



Description of Labor Saved

Replacing the pipe with a stud significantly reduces fabrication time, because the stud is pre-fabbed. There is no need to cut the pipe to the right length. Installation time is also significantly reduced because there is no need to weld the pipe to the stiffener and to the flatbar. There is only a "double-flux" stud to be shot, which can be done by an electrician. An electrician can install the whole foundation by himself, while the pipefitting and welding trades are completely eliminated from the process.

STUD MOUNTING PLATE METHOD

VIBTECH INC/JJH
4/1/96

Figure 6-2 — Stud Mounting Plate Method

HILTI SYSTEM COLD-WORK ATTACHMENT METHODS

Hilti Corporation has developed a number of fastening systems for industrial and marine applications that support the concept of quick attachment methods for shipboard use on foundations and system attachments. Their systems include Powder-Actuated Fastening, Screw Fastening Systems and Anchor systems. They have developed a channel installation system that will facilitate the lattice work system discussed previously. A description of the system components and some applications is included herewith.

JOINER BULKHEAD ATTACHMENT METHODS:

OVERVIEW

Metal joiner bulkheads were originally designed to act as compartment boundaries and could not sustain very high loads. They were capable of carrying only 30 pounds of equipment for each 4-foot x 8-foot panel while sustaining a shock load. However, in the early 1970’s, during the FFG-7 detail design, it was demonstrated that joiner bulkheads could be designed to sustain up to 350 pounds while being subjected to shock. A major benefit of the FFG-7 design development was that nearly 400 deck-to-deck foundations were eliminated by directly mounting equipment to the joiner bulkheads.

As design development continued over the years, appropriate design tradeoffs were made to consider a full load shock-hardened capability versus a reduced capability in order to provide a graduated shock performance structural capability. This graduated capability was considered necessary in order to provide the requisite structural load capability where equipment weights were known. Where future upgrade/future growth flexibility was considered necessary for planning purposes, a minimum shock performance could be provided. Consequently a structural capability to carry 350 pounds and 150 pounds for full load and minimum load, respectively in a grade "A" shock environment was established as a standard by virtue of the example set by the FFG-7 class ships, In order to assess the bulkheads for the purpose of this trade-off, the following rating system was used:

1.0 = Bulkhead is full-load shock rated. The joiner

bulkhead system can support a 350-pound shock load without further development.

0.8 = Panel can definitely support the minimum (150-pound) load and the maximum (350-pound) load with appropriate development.

0.6 = Panel will require moderate development and testing in order to achieve a minimum and maximum load rating.

0,4 = Panel will require development to be able to support the minimum load, and will probably not be able to support the maximum load.

0.2 = Bulkhead system will only support the required 30 pound load under grade "A" shock.

0.0 = Panel will not support any load.

For the purpose of this report, only single-faced fasteners are described, since through-bolting may be unacceptable in decor areas. The load carrying capability of a panel is mainly a function of the thickness of the face sheet for single-face fastener systems, With the use of through-bolting and better design of attachment to coaming and curtain plate tracking systems, it is conceivable that the load carrying capability could be enhanced significantly. For single-face fasteners, the load carrying capability could go as high as 350 pounds under grade

"A" shock. Commercial loads could be much higher due to lower “g” factors. Panel attachment to the tracking system would have to be redesigned and equipment fastener system would have to be designed to take this load.

It has been established that extruded aluminum panels, both 0.055-inch thick (2 psf) and 0.072-inch thick (3 psf) as well as the 0.045-inch thick face sheets on the aluminum honeycomb panels can support the maximum 350-pound load under grade "A" shock These results have been substantiated by tests and are accepted for use by Navy. Since any 0.045-inch thick aluminum-faced panel can withstand the maximum required load, it follows that the aluminum-faced Nomex can as well. Using similar methods of calculation to determine an equivalent load carrying capability panel, a 0.025-inch thick steel face on a Nomex core can handle a 150-pound loading under grade "A" shock. For a steel panel that is equivalent in weight to an aluminum honeycomb panel, a 0.016-inch thick steel face can also carry 150 pounds under grade "A" shock. Thus, any of the panels that have a 0.025-inch steel face or a 0.016-inch steel face can carry loads of up to 150 pounds. Calculations from manufacturers indicate that GRP Nomex is also be able to carry a 150-pound load under a grade "A" shock, and will be able to go as high as 350 pounds with some development. Because of Marinite's unique structure, single face fasteners could not carry any load at all under a grade "A" shock loading, because the equipment would have to be attached with screws into the panel and the plaster-like composition could not handle the stresses considered.

Through bolting, along with the use of backing plates and other methods, enhances the load carrying capability of the panels considerably. The 0.016-inch steel-faced panel could conceivably carry a 350-pound grade "A" shock load. The present method of attaching equipment to Marinite is to run a steel beam behind the panel, supported by a separate foundation, and attach the equipment directly to the beam through the panel. This is contrary to the whole idea of eliminating the through-bolting method to reduce weight and cost.

Another facet that should be considered is the panel's load carrying capability when subjected to fire. Aluminum-faced panels performed the worst in this area. After 3.5 to 5 minutes into the fire (as defined by the ASTM E-119 fire test), the aluminum panels melted. Typical damage control response time to a fire is 6 minutes. Thus, system failure would occur and all equipment would be lost before there could be a response to the fire. GRP extends this burn through time to 30 minutes, but failure under a load would occur at no less than O' to 7 minutes depending on the magnitude of the load . The problem is that the resin burns out of the glass, reducing the panels structural strength.

Steel-faced panels perform better than the other candidate bulkhead systems when subjected to fire, since steel neither decomposes nor melts at these temperatures. Steel is much better than GRP Nomex, and GRP Nomex will last about three times as long as aluminum under fire conditions with a load. The Coast Guard conducted C.P,O, berthing compartments burnout tests, which followed the ASTM-119 fire test for the first several minutes. The aluminum melted at 3 to 5 minutes, GRP panels maintained their integrity except in areas where the fire directly impinged on the panel, Steel-faced panels showed no signs of structural failure anywhere. The steel panels used in the C,P,O, burnout tests were steel-faced Nomex,

FIRE CONTAINMENT

In the event of a f ire aboard ship, combat capability can become greatly impaired if the fire spreads beyond of the confines of the compartment in which it originated. A joiner bulkhead system is considered a good f ire stop if it is able to contain a fire until damage control has time to respond. Any containment time less than the time it takes to detect the fire is considered a poor fire stop. Typical response times range from 8.5 minutes to 13.5 minutes, including a 3.5 minute detection time. For the purpose of a trade-off, containment time of 30 minutes is considered the "top end" of the scale since any fire contained in one area for that length of time could certainly be put out by damage control.

Since welded CRES honeycomb, extruded aluminum, and Marinite are inorganic, they do not burn or smoke. Coast Guard compartment fire tests showed that Marinite panels contained the f ire throughout the life of a 45-minute test.In another Coast Guard full-compartment burn test, six tests were conducted to determine fire and smoke containment capability of various joiner bulkhead systems. Core material for each of the test bulkheads

was Nomex aramid honeycomb, filled with a phenolic foam. Three bulkhead face materials were tested: phenolic resin impregnated fiberglass, galvanized steel, and painted steel.The Coast Guard test simulated a "worst-case" situation without being unreasonably severe. Good control was maintained over the test conditions, consistent with cost constraints, Time- Temperature relationships observed in the testing were compared to the standard fire test method, ASTM –119. While the temperatures in the six fire tests show variability, factors such as the timing and extent of ceiling panel collapse, warpage of bulkhead panels within the tracking system, and heat absorption could not be controlled without decreasing the realism of the test.

FASTENER TESTS

As a basis for establishing the strength of fasteners attached to the honeycomb bulkheads a number of types of fasteners may be attached to small sections of honeycomb bulkhead material in order to be tested independently in tension and shear. The results of these tests are evaluated to establish the design criteria for the strength of the fastening system used to attach equipment to the honeycomb panel.

TENSILE LOADING FAILURE MECHANISMS

For fasteners attached to one face sheet of a honeycombed panel (i.e. single 3/16" diameter pop-rivets and various size press nuts without pads) and subject to a tensile load (load applied normal to the panel): failure occurred by pull out of the fastener. For fasteners attached to a single face sheet with pop riveted pads (i.e. ½" and ¾" welded studs on steel pads and various size Rivnuts with pads) failure occurred by delamination of the face sheet from the honeycomb core. For bolts installed through the honeycomb panels the core collapsed locally in way of the bolts. When Aeronca conducted similar tests on ¼" dia bolts through honeycomb panels they recorded the load at which the panel began to yield locally (core collapsing in way of bolt) as well as the ultimate tensile load required to pull the bolt through the panel.

SHEAR LOADING FAILURE MECHANISMS

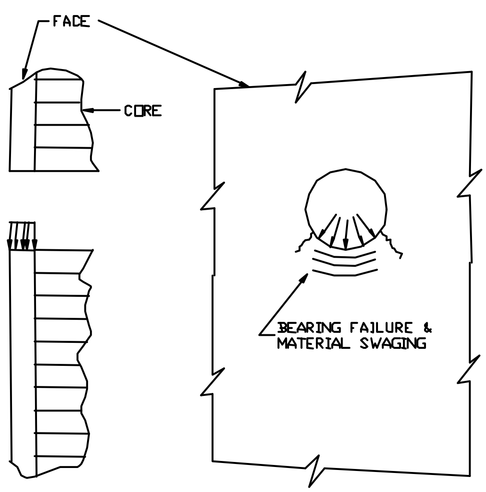
The same types of fasteners as tested above were also subjected to applied shear loads. In three cases the fasteners failed in shear: the ¼" dia bolts threaded into rivnuts installed in honeycomb panels with and without riveted pads failed, the single 3/16" dia pop rivets failed, and the pop rivets attaching the pads with welded studs failed when only four pop rivets were used. All other failures resulted from local failures of the honeycomb panels in way of the fasteners. For bolts larger the an ¼" and threaded into press nuts and rivets which were installed in one face (with no pads) breaking failure of the face sheet occurred, accompanied by local core crushing due to rotation of the insert in the panel. For rivnuts larger than ¼" dia bolt capacity and inserted into one face through pop riveted pads, failure occurred by panel buckling due to the overturning effect of the eccentrically loaded bolts. There was no evidence of bearing failures in the panel face sheets in way of these fasteners. When a shear load was applied to ½" and ¾" studs welded to steel pads the pop rivets attaching the pads to the honeycomb panels failed in shear if less than 4 pop rivets were used. When 8 pop rivets were used failure occurred by panel buckling similar to that observed for rivnuts through pads. For the 5/8", ½" and ¾" dia through bolts (no pop-riveted pads) bearing failures occurred in both faces of the panel. In all cases the through bolts rotated in the holes due to the eccentrically applied shear loads. When pop riveted pads were installed on the side of the applied shear load the panels again buckled (except that when only 4 pop rivets were used to install the pad and the ¾" dia through bolt was tested all four pop rivets sheared and bearing failures at the bolt in both panel faces). In general, the ultimate failure loads were those loads that caused local panel failures in way of the fasteners (face sheet bearing failure, core crushing and local panel buckling). The only cases where actual fastener failures were recorded were the shear failure of pop rivets (either alone or fastening pads to the panels) and the shear failure of the ¼" dia bolts threaded into rivnut inserts.

CONCLUSION

The results of the tests as outlined in the preceding two paragraphs indicate that the honeycomb panel face sheet failure rather than actual fastener failure is the predominant mode of attachment failure. In order to account for the interaction of the tensile and shear loads when applied to the honeycomb attachments simultaneously suitable interaction equations have been developed.

INTERACTION EQUATIONS

It must be first noted that all tensile and shear tests were run independently. It is therefore impossible to draw any conclusions as to the interactive effects of combined tensile and shear loading from the test program. In order to determine the ultimate strength of the various honeycomb fastener configurations under combined tension and shear the stress ratio interactive curve method developed by Shanley was employed. In this method the stress conditions on the honeycomb face sheets are represented as stress ratios. For a simple stress, the stress ratio can be expressed as,



SHEAR LOAD

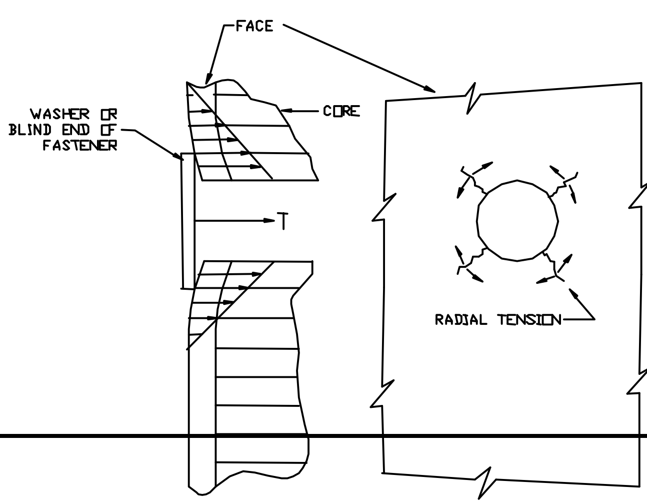
$$R = \text{Stress Ratio} = f / F$$

Where f is the applied stress and F is the allowable stress

For combined loading, the general conditions for failure are expressed by Shanley as

$$R_1^x + R_2^y + R_3^z = 1 \quad (1)$$

R_1, R_2, and R_3 could refer to tensile, bending and shear. The exponents give the relationship for the combined stresses. The exponents of the stress ratios in the above equation can be determined by various well-known theories of yield and failure. However in many cases of combined loading for specific structural configurations the exponents must be determined by making failure tests of the combined load system. The interaction equation may also be written in terms of load ratios rather than stress ratios. Where f is the applied load and F is the maximum allowable load.



DUE TO SHEAR LOAD

Considering the panel face as a stiffened web plate it can carry a shear load larger

than the load required to cause local crippling (buckling) in way of the hole.

If the bearing stress is not limited to the bearing capacity of the face material, local buckling bearing failure in way of the hole would be the anticipated failure mode.

Due to Tensile Load

Maximum transverse shear occurs at the periphery of the washer. This shear decreases in intensity away from the washer due to larger area involved. This maximum shear does not occur at the point of maximum bending.

CONCLUSION

The above sections show the typical types of loading expected in the honeycomb face sheets in way of the fasteners. It can be seen that the predicted maximum bearing load, transverse shear load and bending moment do not occur at the same point. Well known theories of yield and failure give techniques for calculating the combined stresses resulting from the bearing load, transverse shear and bending moment but they give no techniques for adding the effects of radial tension and material swaging in way of the fastener. It is obvious that these effects can combine to lower the effective strength of the various fastener configurations. Because no methods other than actual testing are available to account for these effects the BIW testing program was devised to give ultimate failure loads in tension and shear independently. To account for the interactive effects of these two load cases, since no combines load cases were tested, the most conservative form of Equation (1) was chosen:

$$R_1 + R_2 + R_3 = 1 \qquad (2)$$

The exponents x, y, and z were set to one. R_1 equals the ratio of the applied tensile load to the allowable tensile load and R_2 equals the ratio of the applied shear load to the allowable shear load.

The final form of equation (1) to be used is as follows:

$$T / T_{allow} + S / S_{allow} < 1 \qquad (3)$$

ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

BACKGROUND / APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16". However, it may be possible to broaden the use of robots through the use of standard construction details for both structure and outfit and especially equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards..

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant "MAP" would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness & other characteristics) in order to complete the weld or other construction sequence.

The robot with "3-D" vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach pendant will orient the robot to its work and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvement in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for "actual" distortions, skewness and irregularities will usher in advanced applications for robots.

TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, limitations in following prescribed tool path. Characterize state of the art in 3-D vision systems and teachable robots
2. Define parameters for the constraints on robots, standards, 3-D vision systems and teach pendant systems.
3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.
4. Select Candidate structural/ outfitting details, portable robotic systems, 3-D vision systems and teachable control systems to develop candidate applications for portable robotic systems.
5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

APPENDIX A — SMART SYSTEMS

SMART SYSTEMS

Shipboard

Modular

Arrangement

Reconfiguration

Technology

ATC
AFFORDABILITY THROUGH COMMONALITY

SMART SYSTEM COMPONENTS

- SMART Track/Deck
  - Track
  - MIL Track Installation
  - COTS Track Installation
  - Fittings
- Modular Furniture
- Modular Power
- Modular Lighting

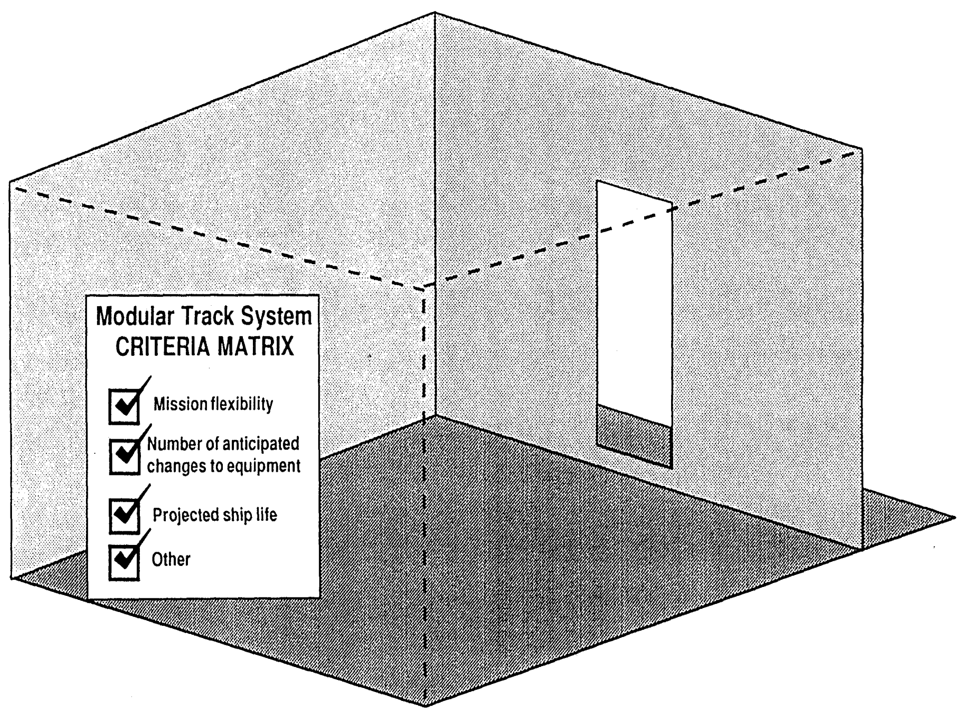
TYPICAL SMART SYSTEM INSTALLATION

- Determine candidate SMART Deck space using Modular Track Systems Criteria Matrix
- Perform deck/bulkhead survey to determine area & track orientation, and Hard vs. Soft Track requirements.

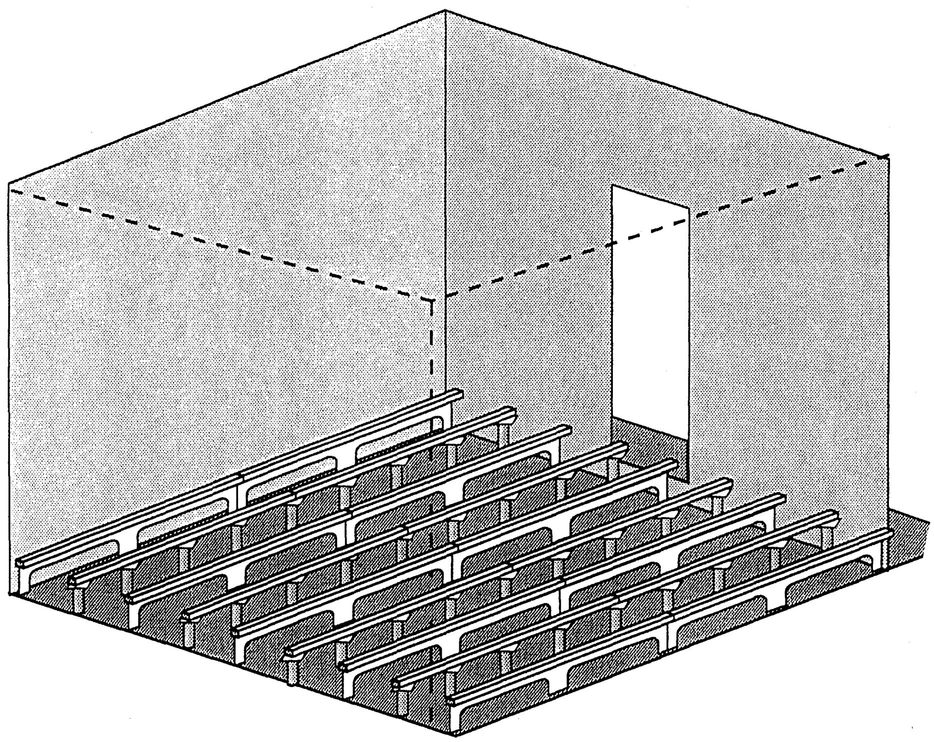
HARD TRACK [MIL SPEC]		SOFT TRACK [COTS]
•Size & Install Hard Track Foundation Support System	OR	•Weld or Bolt Soft Track Foundation Support System

- Install Track Adapters
- Install SMART Track
- Install Longitudinal Supports
- Install Deck Panels/Filler Strips
- Install Equipment Foundation Fittings and Adapters
- Install Equipment Foundations and Equipment

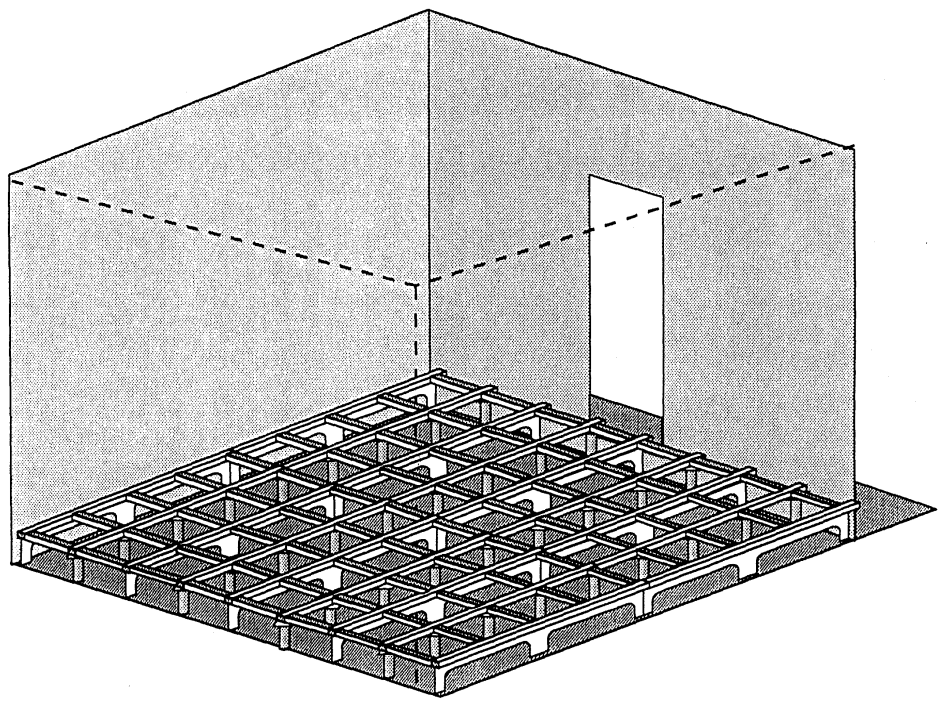
DETERMINE CANDIDATE SMART SPACE



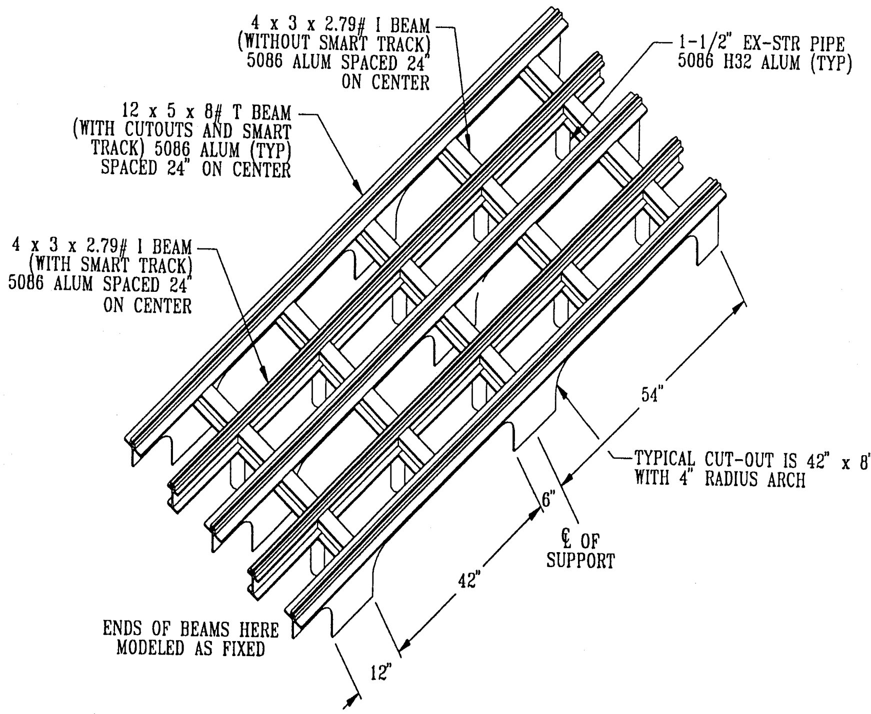
H/D SMART TRACK INSTALLED ON "HARD TRACK" FOUNDATIONS

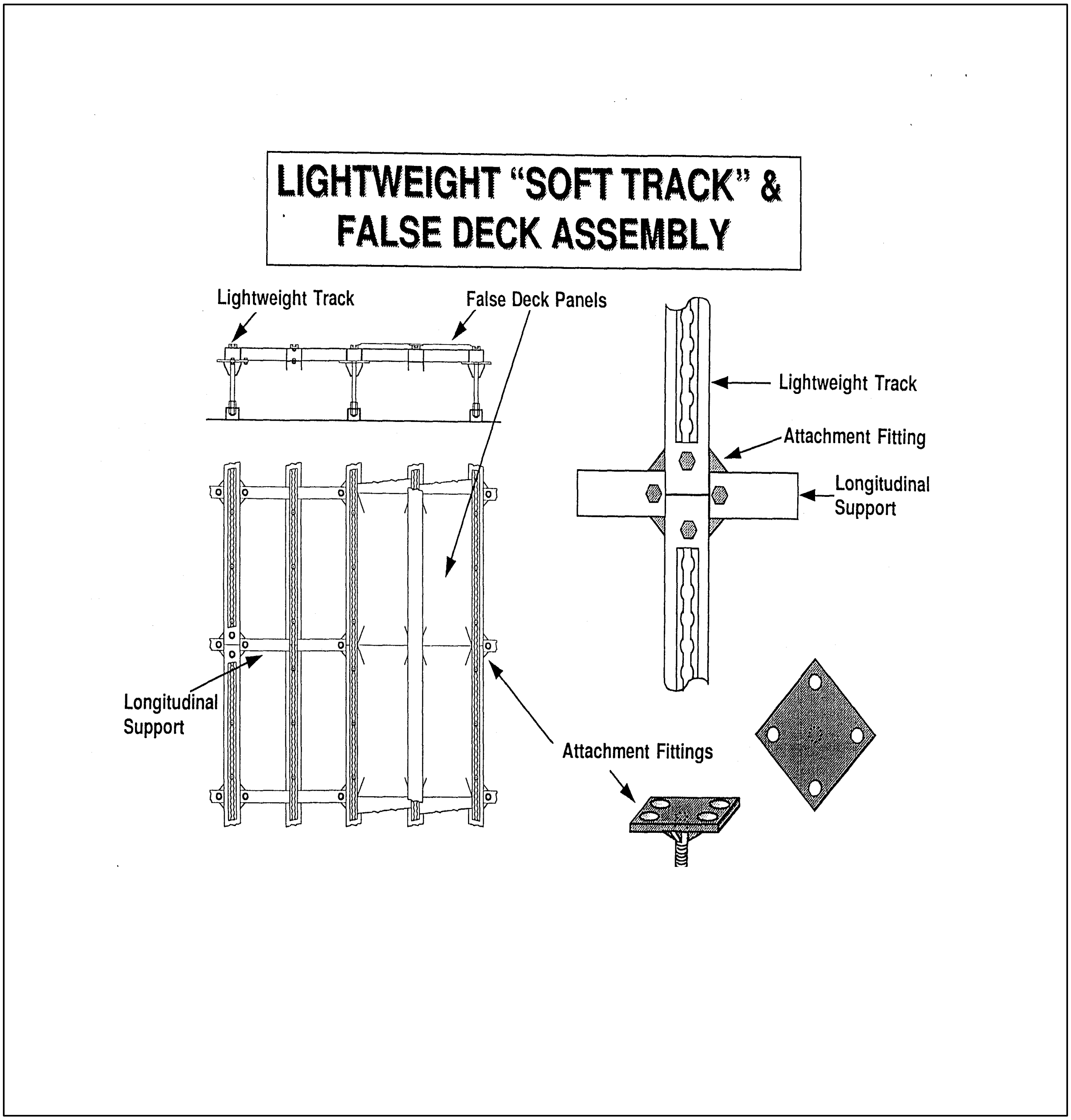


"HARD TRACK" LONGITUDINAL SUPPORTS INSTALLED

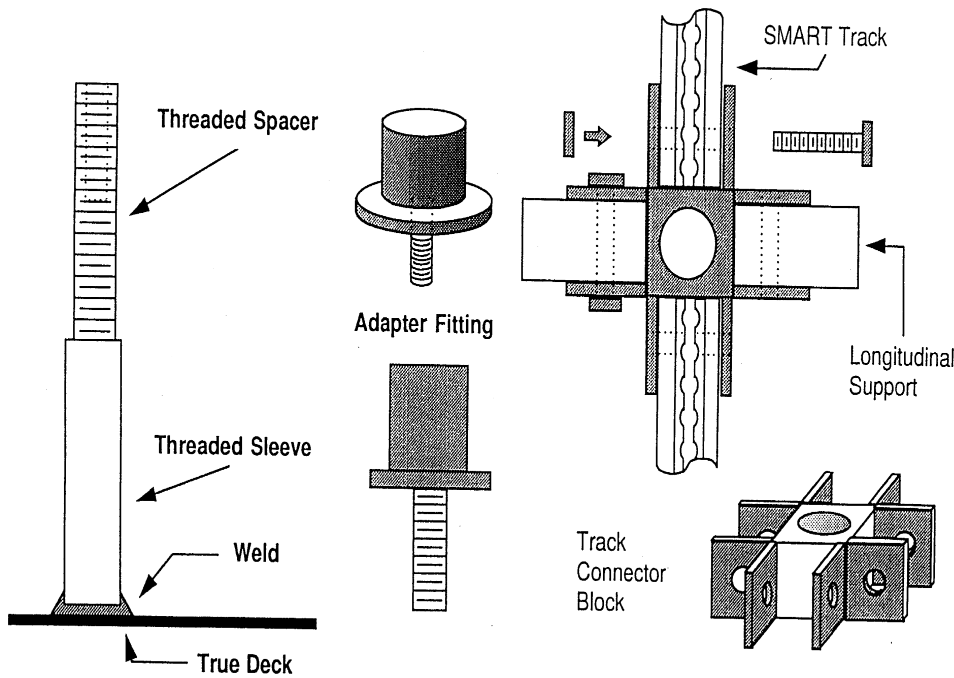


DETAIL OF HEAVYWEIGHT MILSPEC "HARD TRACK" ASSEMBLY

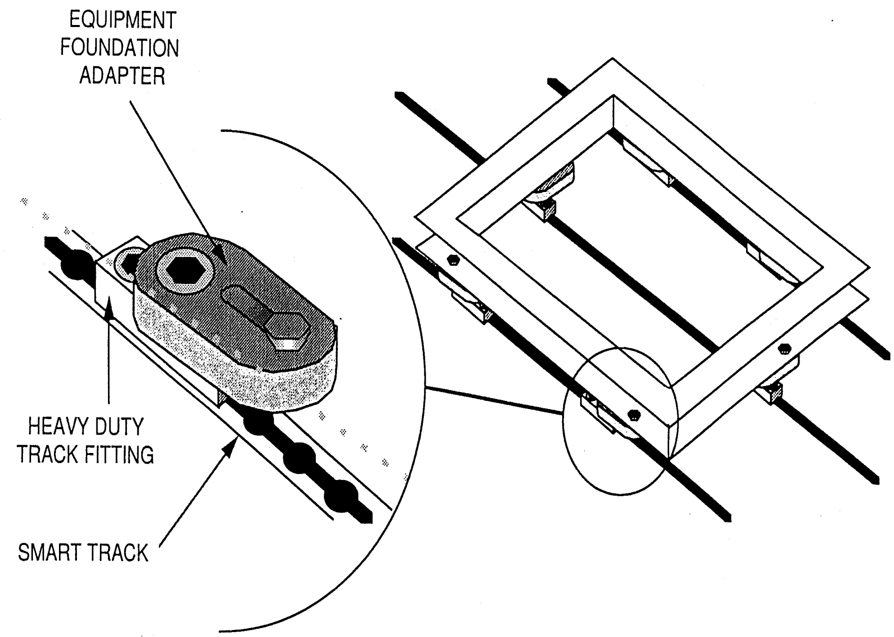



LIGHTWEIGHT "SOFT TRACK" &
FALSE DECK ASSEMBLY
Lightweight Track
False Deck Panels
Lightweight Track
Attachment Fitting
Longitudinal Support
Longitudinal Support
Attachment Fittings

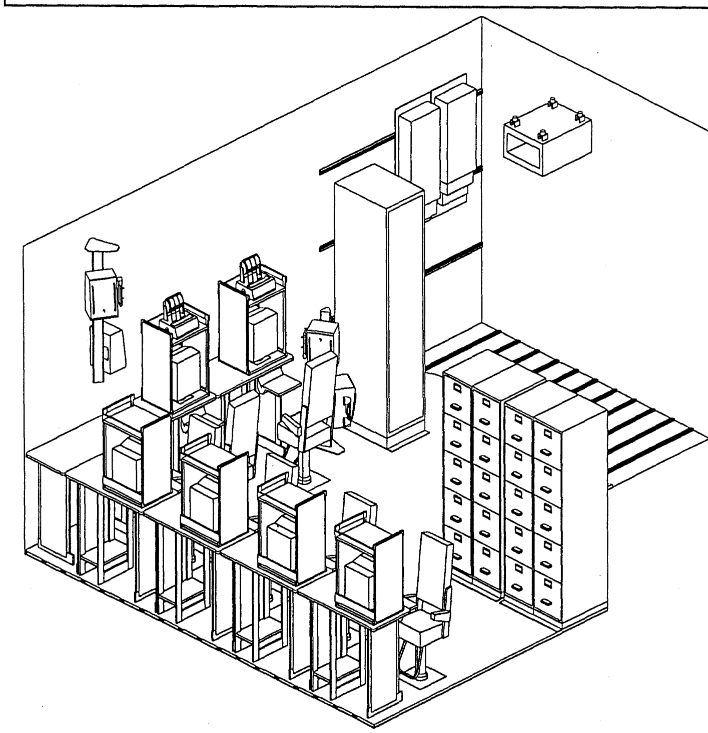
MEDIUM/HEAVY WEIGHT SPACER, ATTACHMENT FITTING AND ASSEMBLY



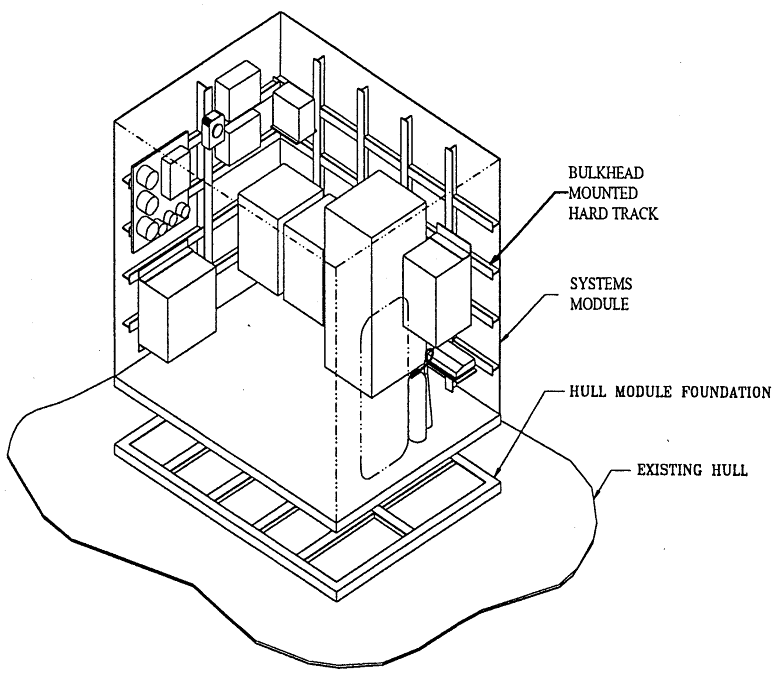
TYPICAL EQUIPMENT FOUNDATION WITH HEAVY DUTY TRACK FITTINGS & FOUNDATION ADAPTER



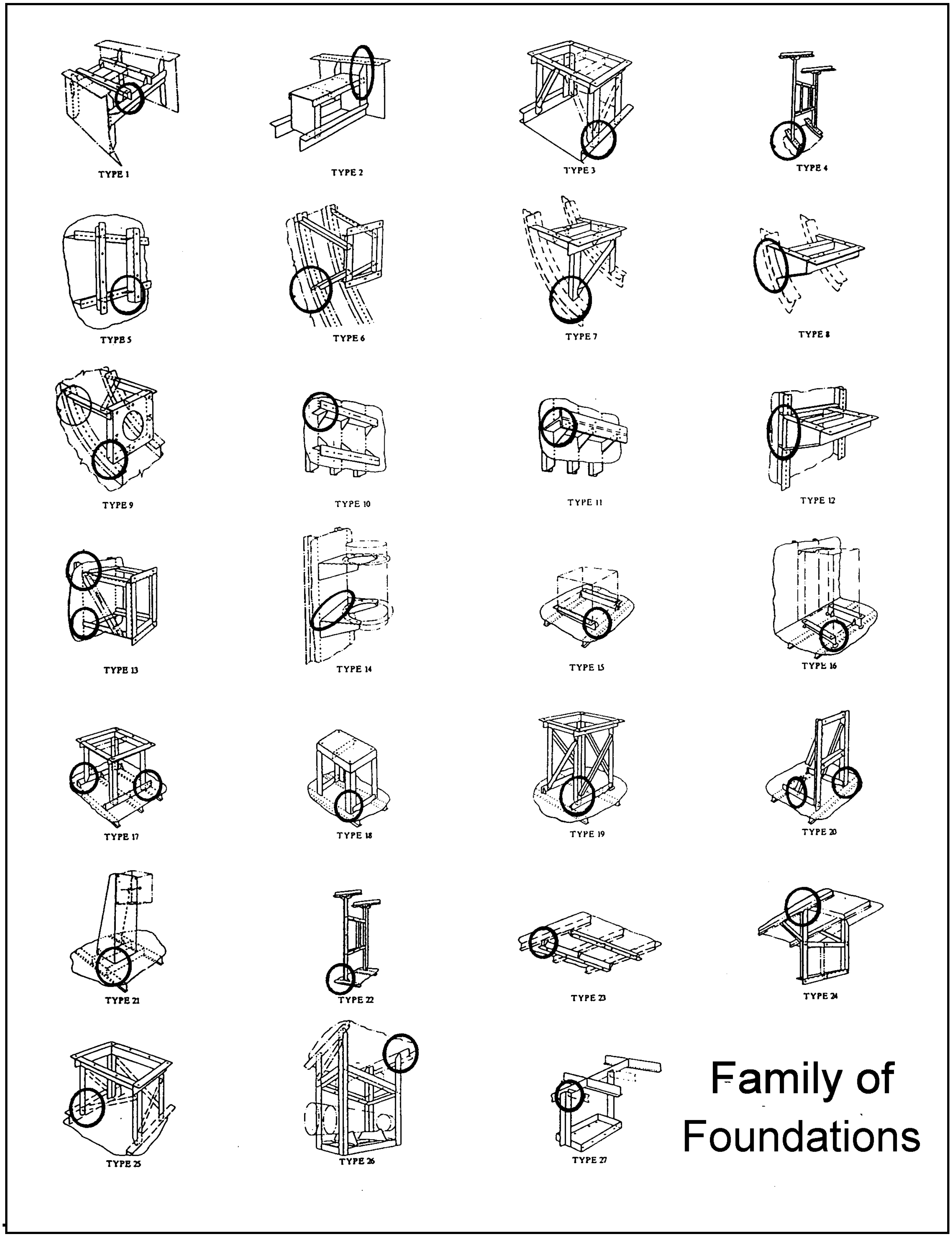
SMART SPACE: INCORPORATES SMART DECK, SMART EQUIPMENT FOUNDATIONS, AND MODULAR POWER DISTRIBUTION, LIGHTING AND FURNITURE

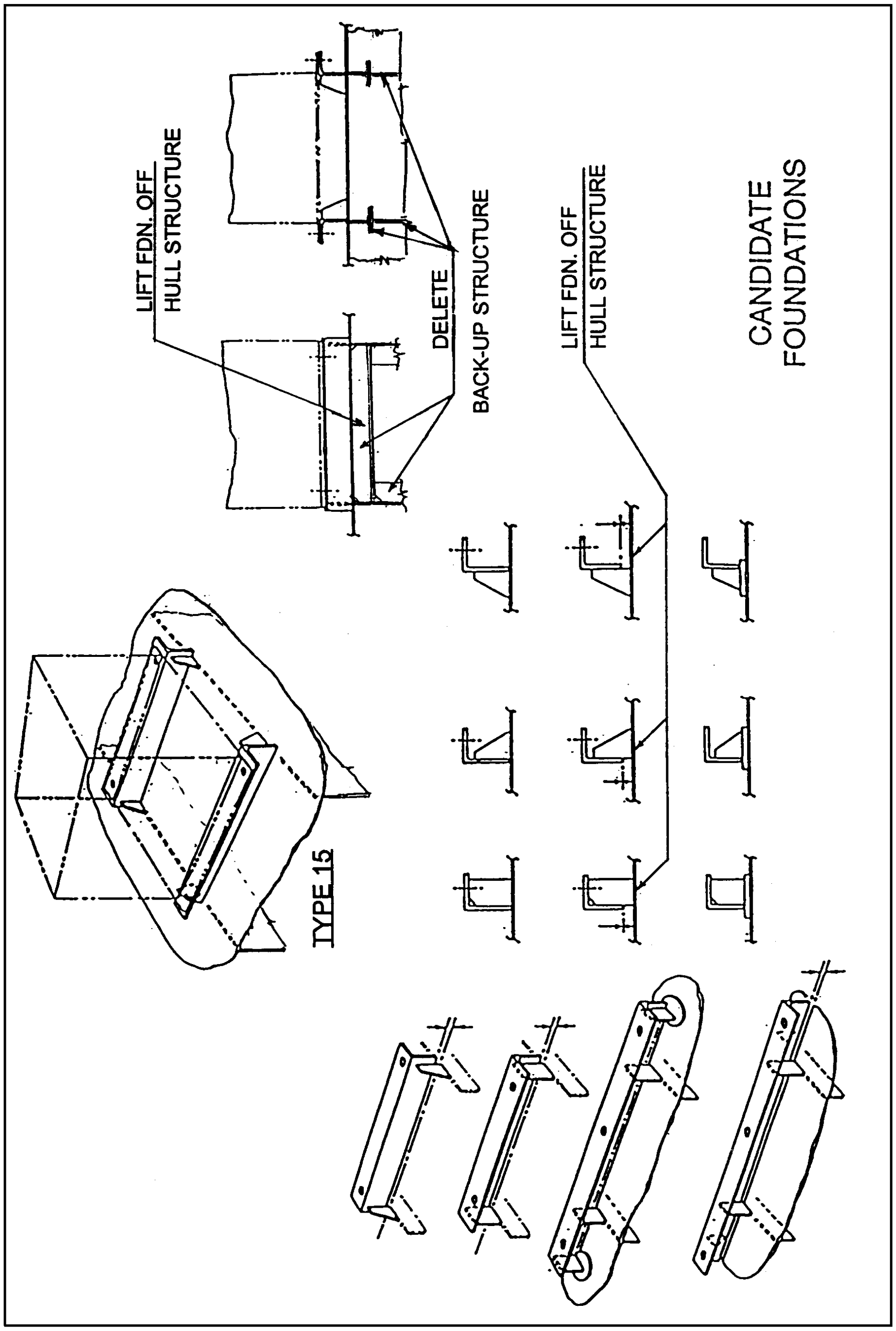


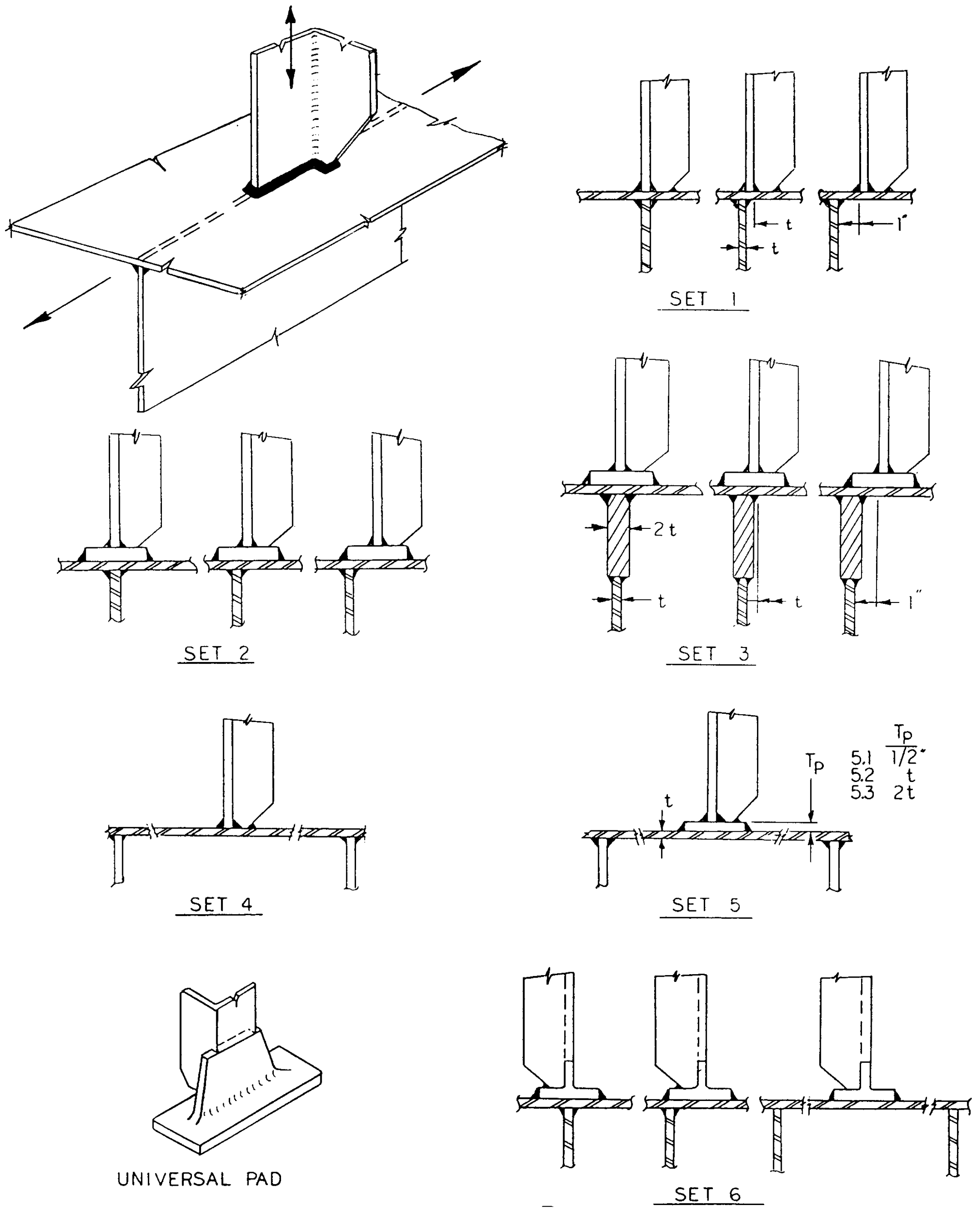
PREFABRICATED SMART SYSTEMS MODULE: EQUIPMENT CAN BE PRE-ASSEMBLED OFF-SITE FOR INSTALLATION/INTEGRATION AT SHIPYARD



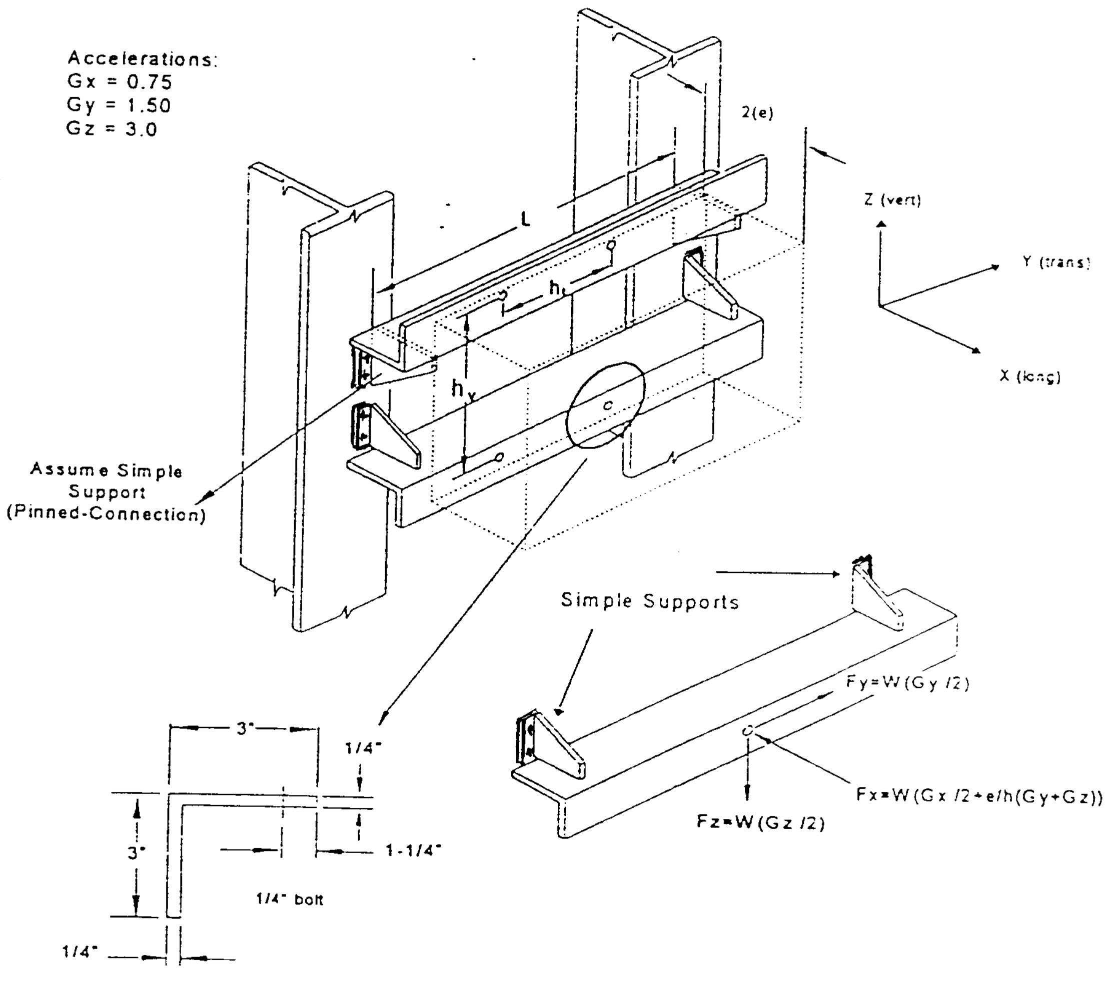
APPENDIX B — FAMILY OF FOUNDATIONS WITH ALTERNATIVE ATTACHMENT TECHNIQUES

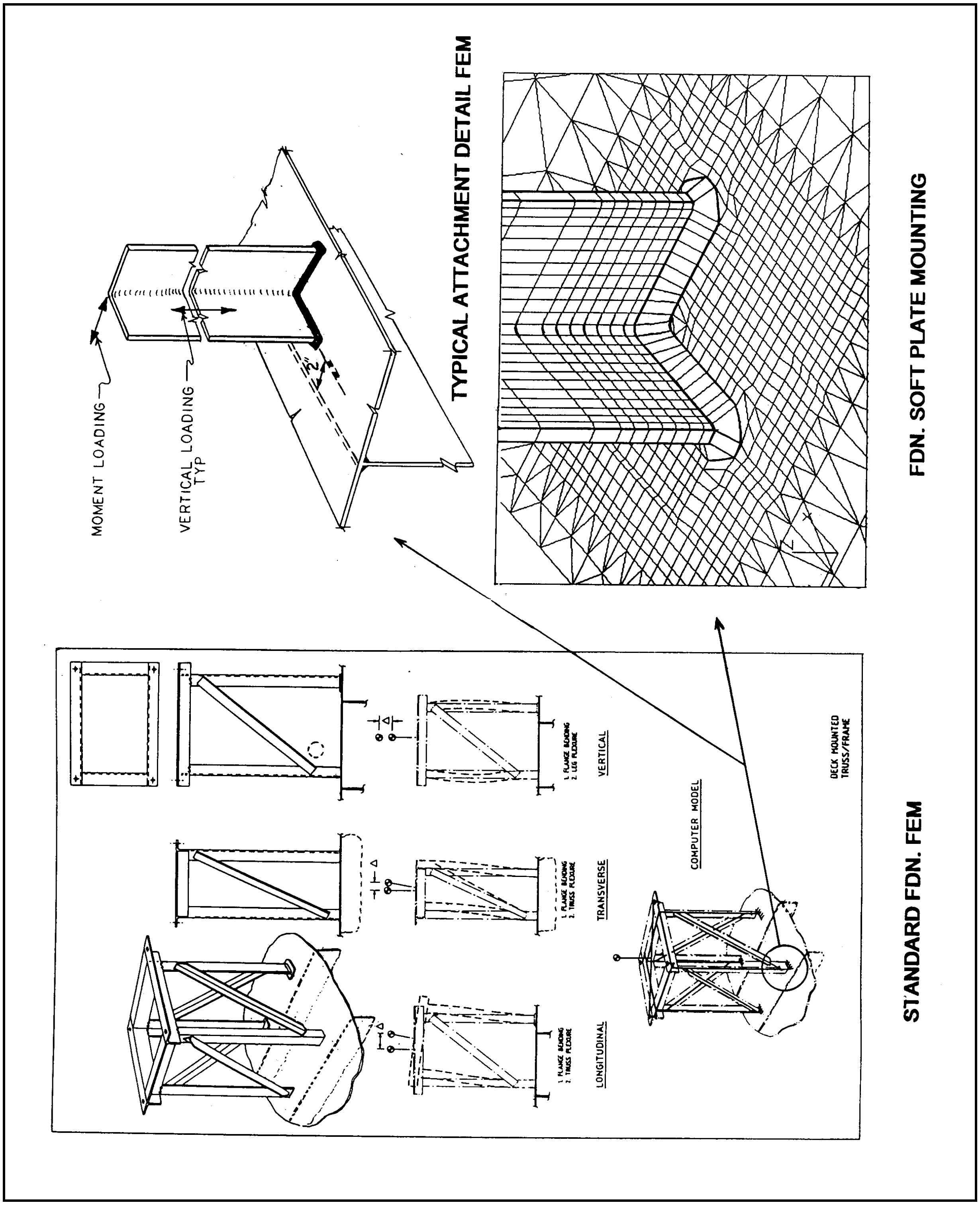

TYPE 1
TYPE 2
TYPE 3
TYPE 4
TYPE 5
TYPE 6
TYPE 7
TYPE 8
TYPE 9
TYPE 10
TYPE 11
TYPE 12
TYPE 13
TYPE 14
TYPE 15
TYPE 16
TYPE 17
TYPE 18
TYPE 19
TYPE 20
TYPE 21
TYPE 22
TYPE 23
TYPE 24
TYPE 25
TYPE 26
TYPE 27
Family of Foundations


LIFT FDN. OFF
HULL STRUCTURE
DELETE
BACK-UP STRUCTURE
LIFT FDN. OFF
HULL STRUCTURE
CANDIDATE
FOUNDATIONS
TYPE 15

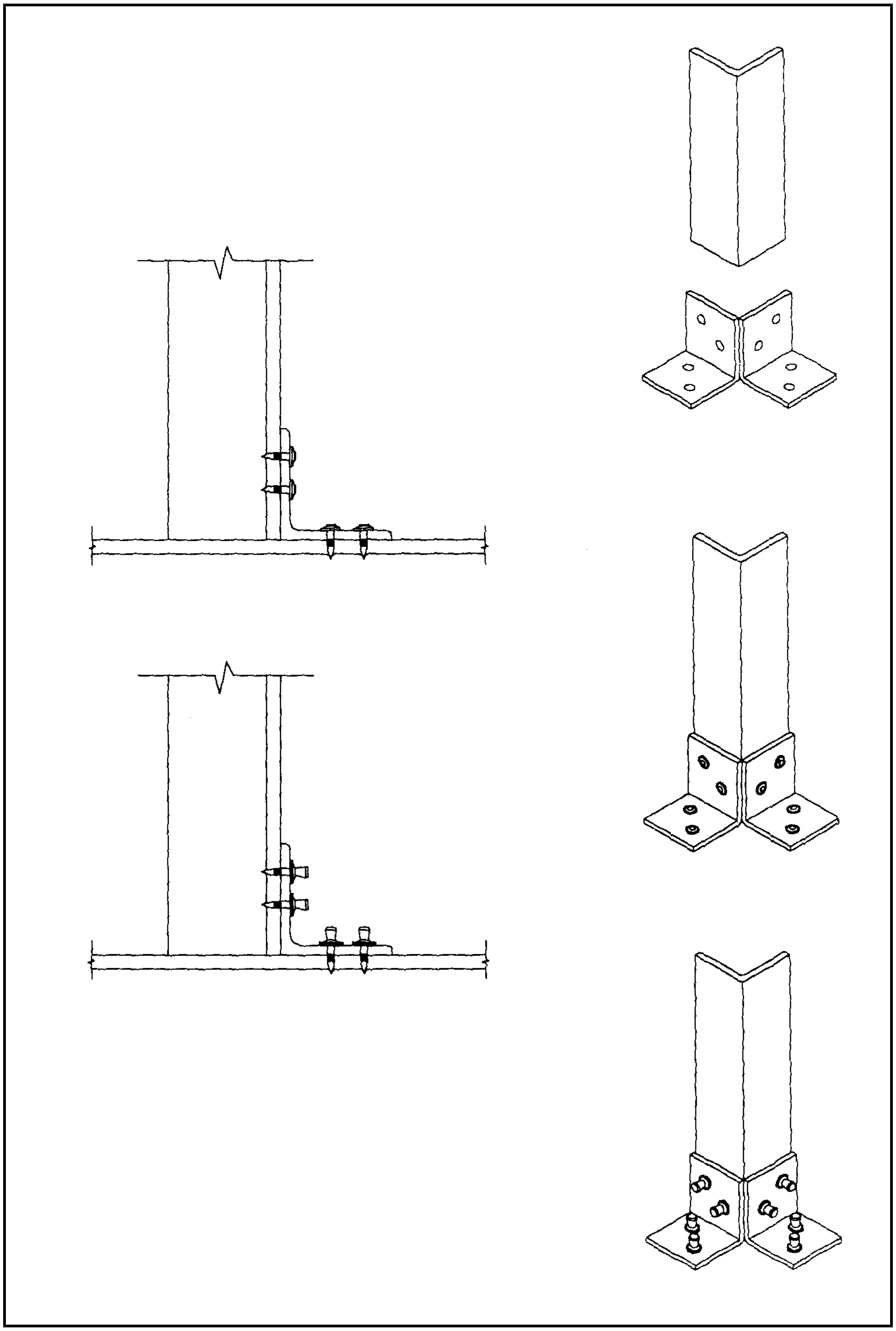


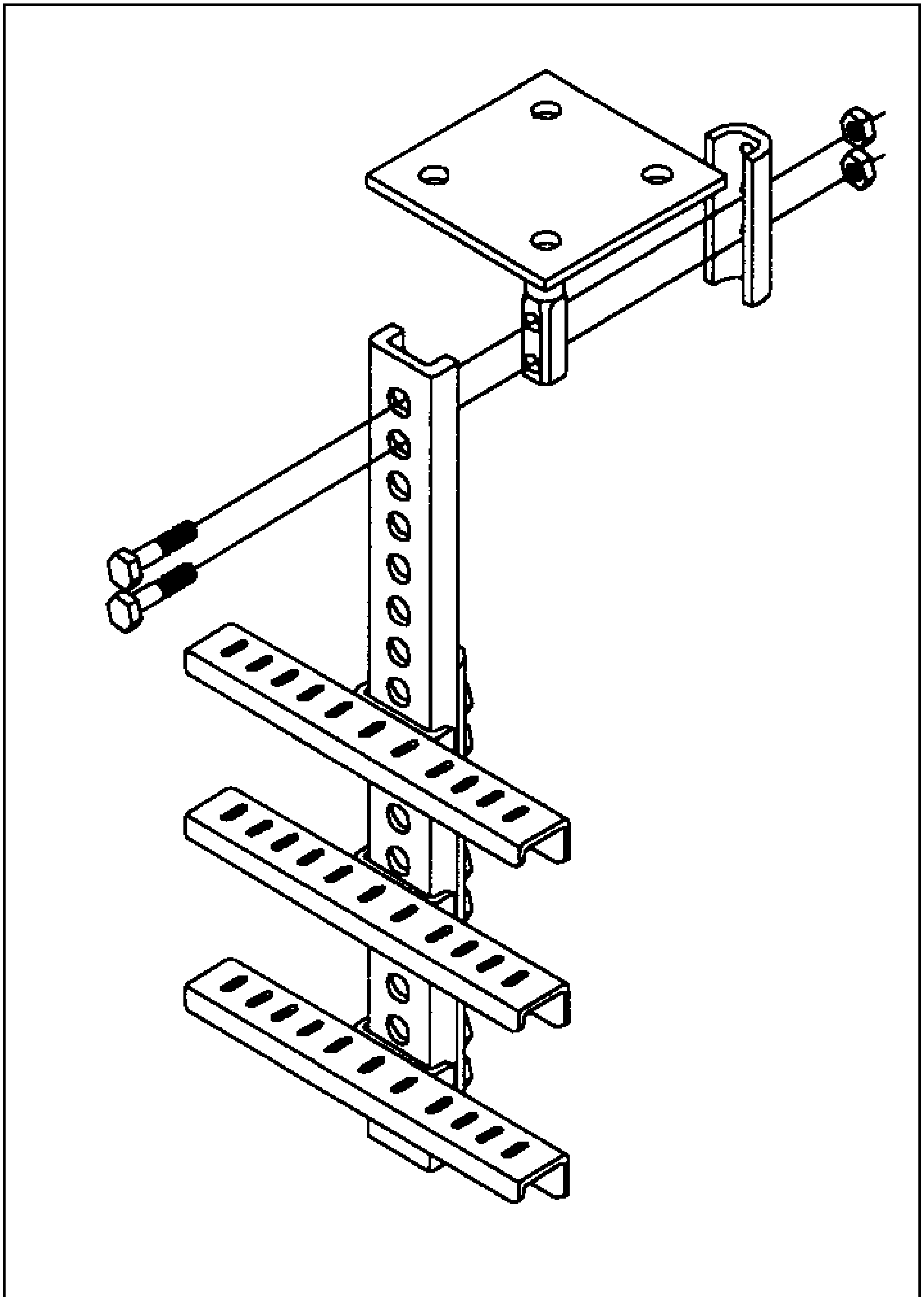
FOUNDATION ATTACHMENT DETAILS

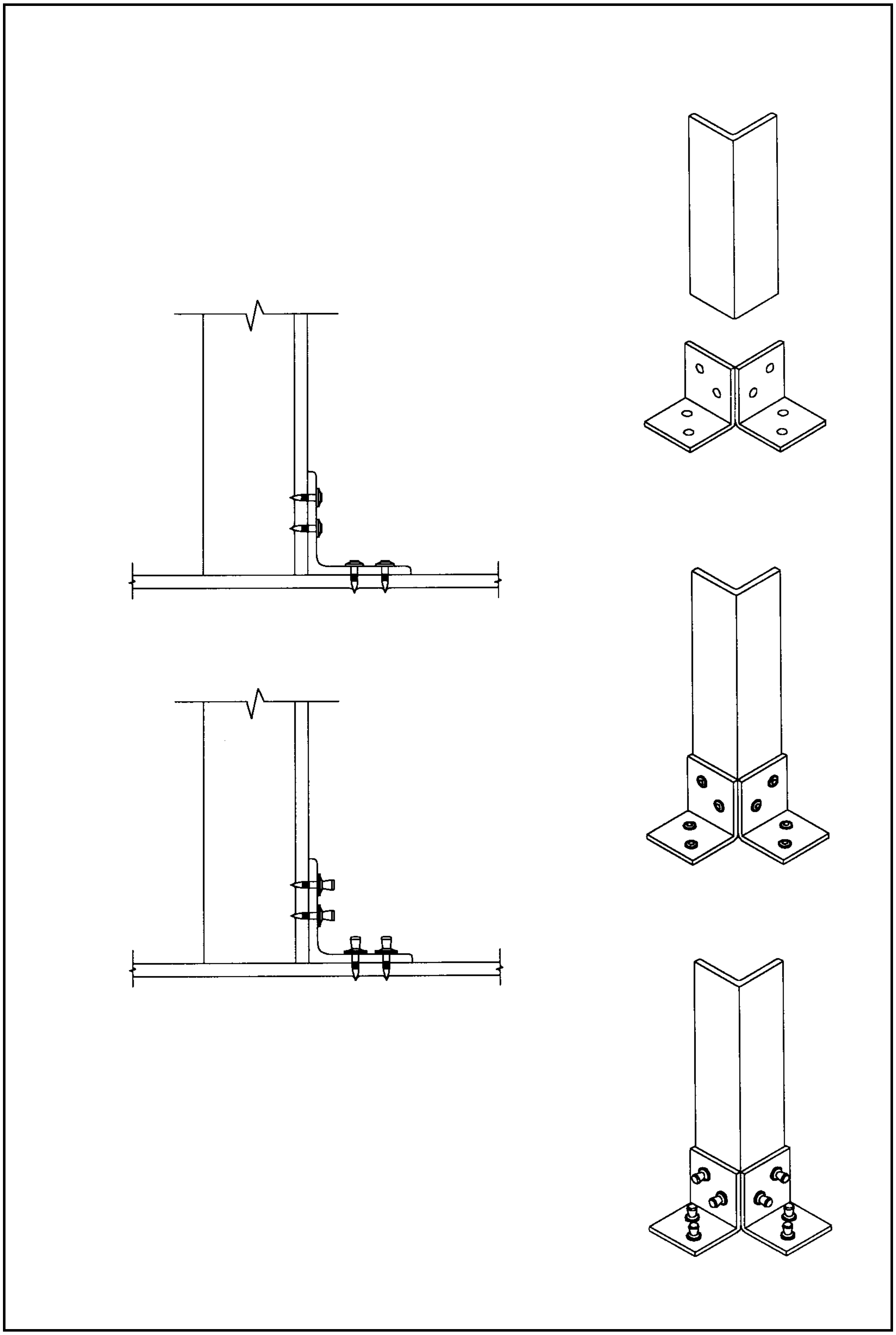

Accelerations:
Gx = 0.75
Gy = 1.50
Gz = 3.0
2(e)
L
h
Z (vert)
Y (trans)
X (long)
Assume Simple
Support
(Pinned-Connection)
Simple Supports
Fy=W(Gy /2)
Fx=W(Gx /2+e/h(Gy+Gz))
Fz=W(Gz /2)
3"
1/4"
3"
1-1/4"
1/4" bolt
1/4"

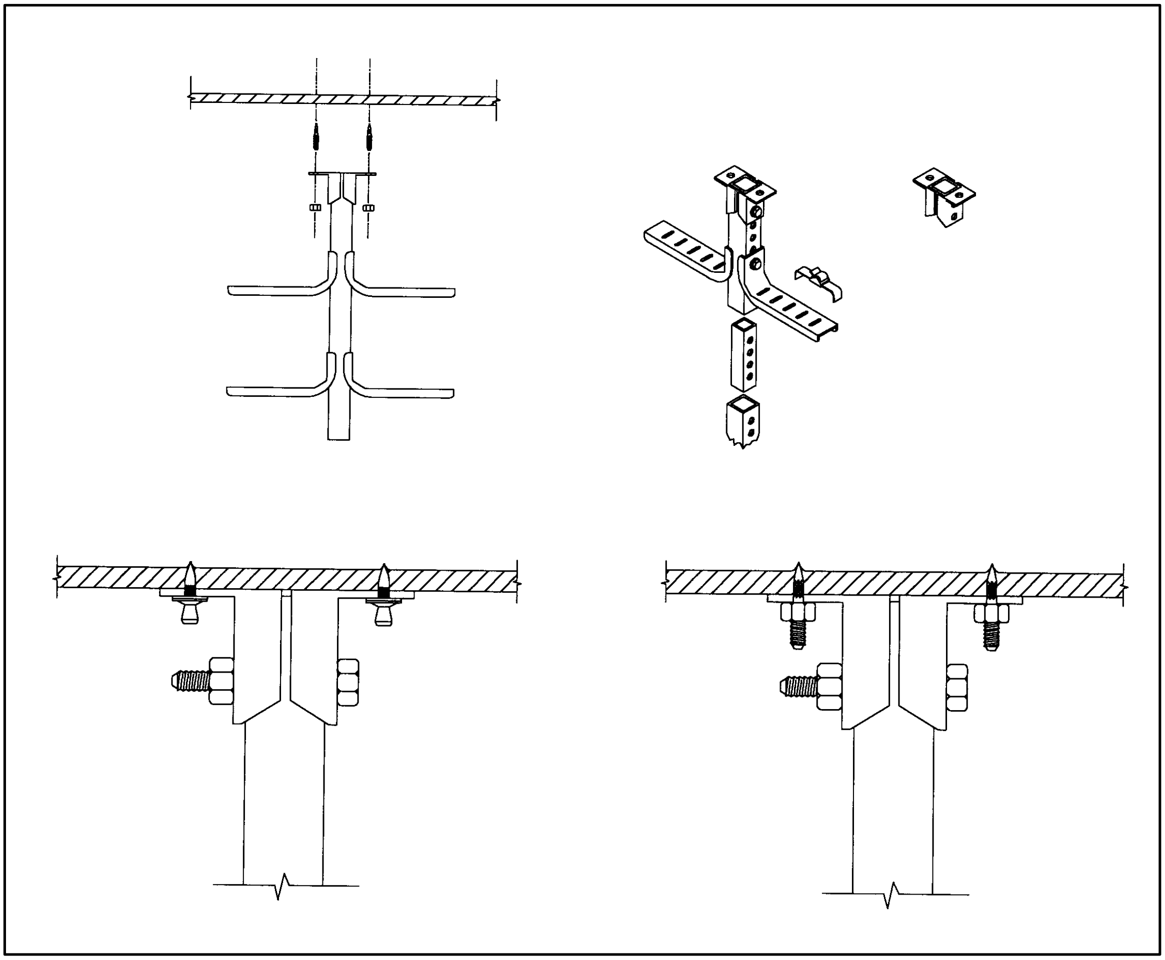

TYPICAL ATTACHMENT DETAIL FEM
MOMENT LOADING
VERTICAL LOADING TYP
FDN. SOFT PLATE MOUNTING
LONGITUDINAL
TRANSVERSE
VERTICAL
COMPUTER MODEL
DECK MOUNTED TRUSS/FRAME
STANDARD FDN. FEM

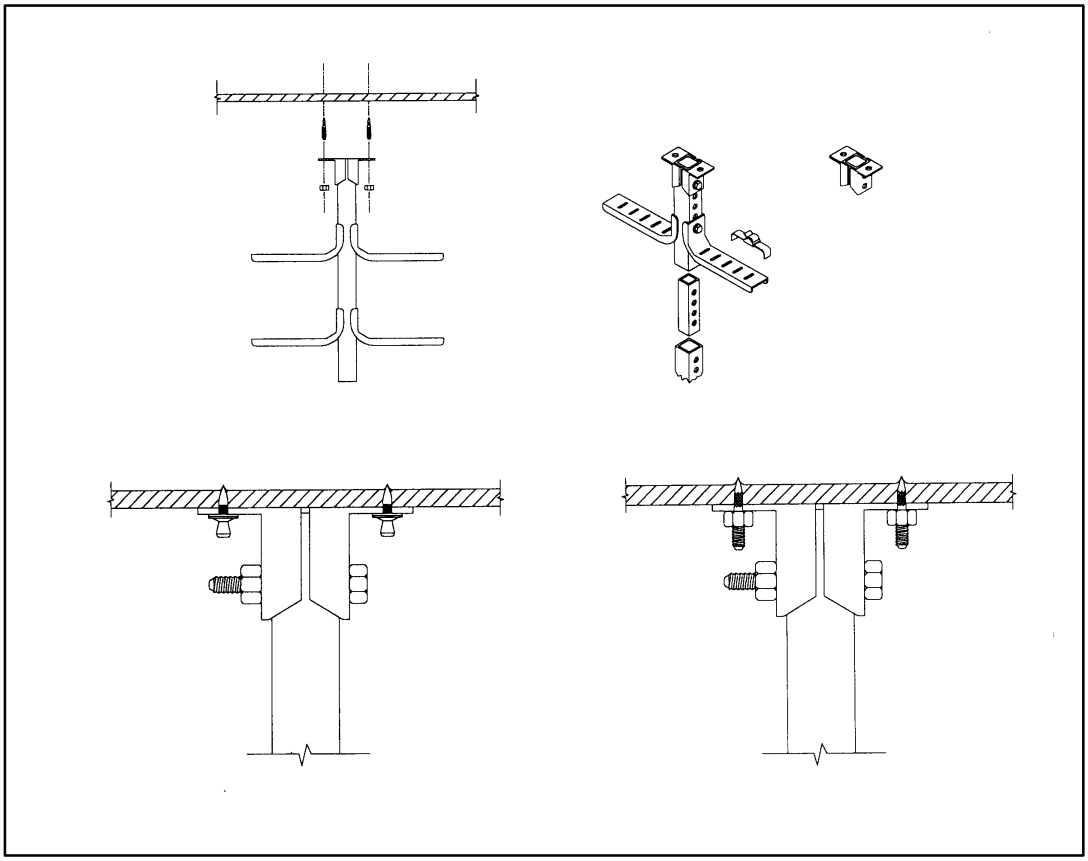
APPENDIX C — HILTI SYSTEM ATTACHMENT TECHNIQUES

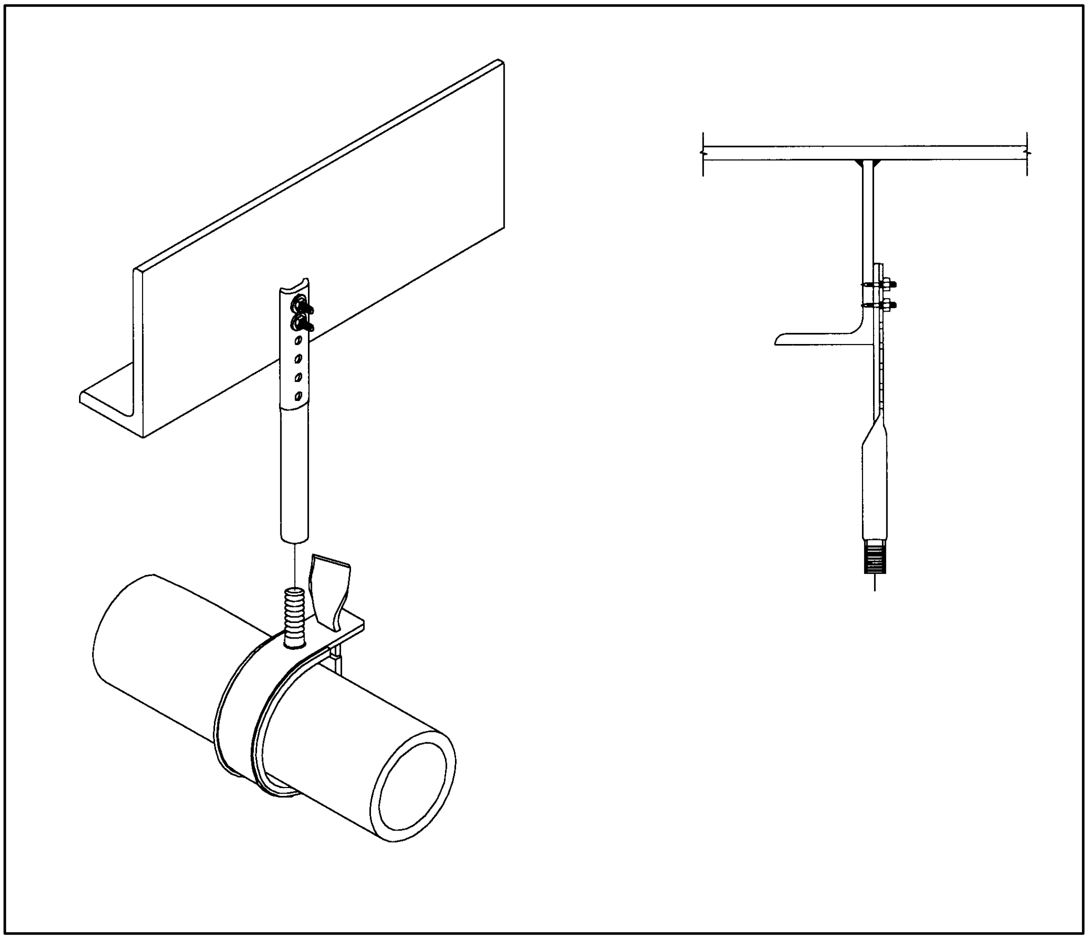


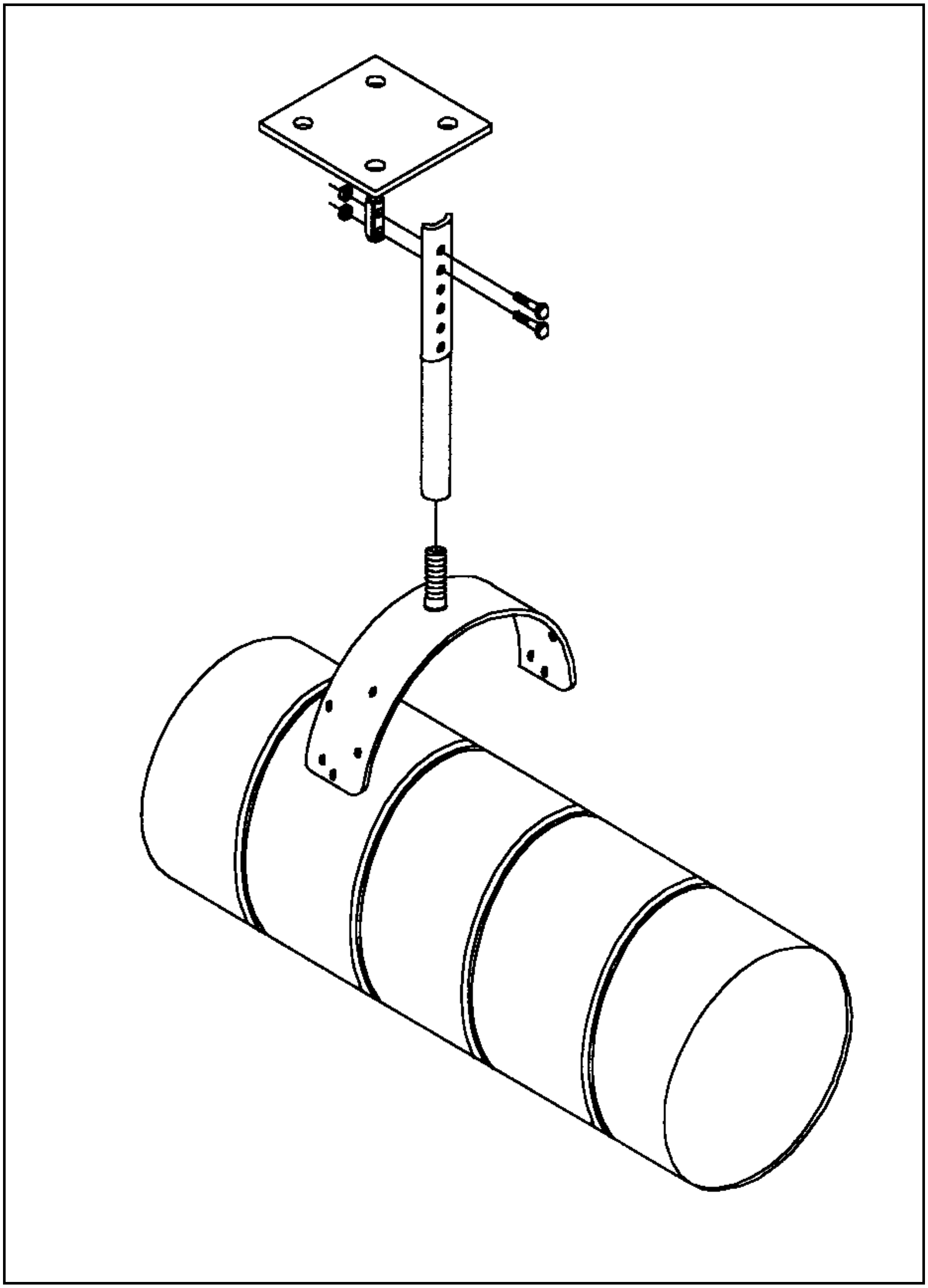






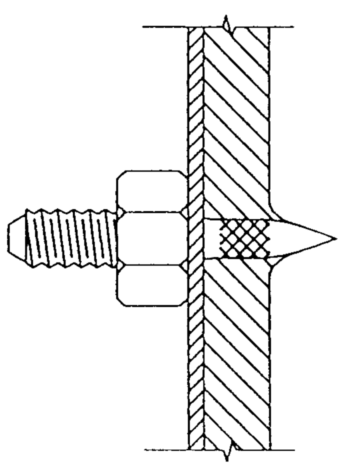




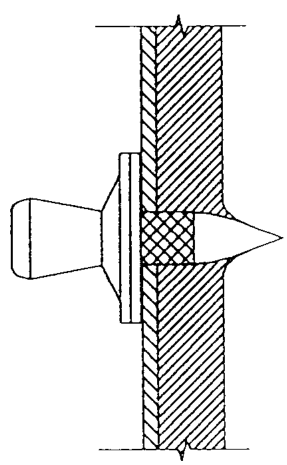


HILTI Fasteners

EW6H - Threaded Stud



ENPH2 - High Strength Nail



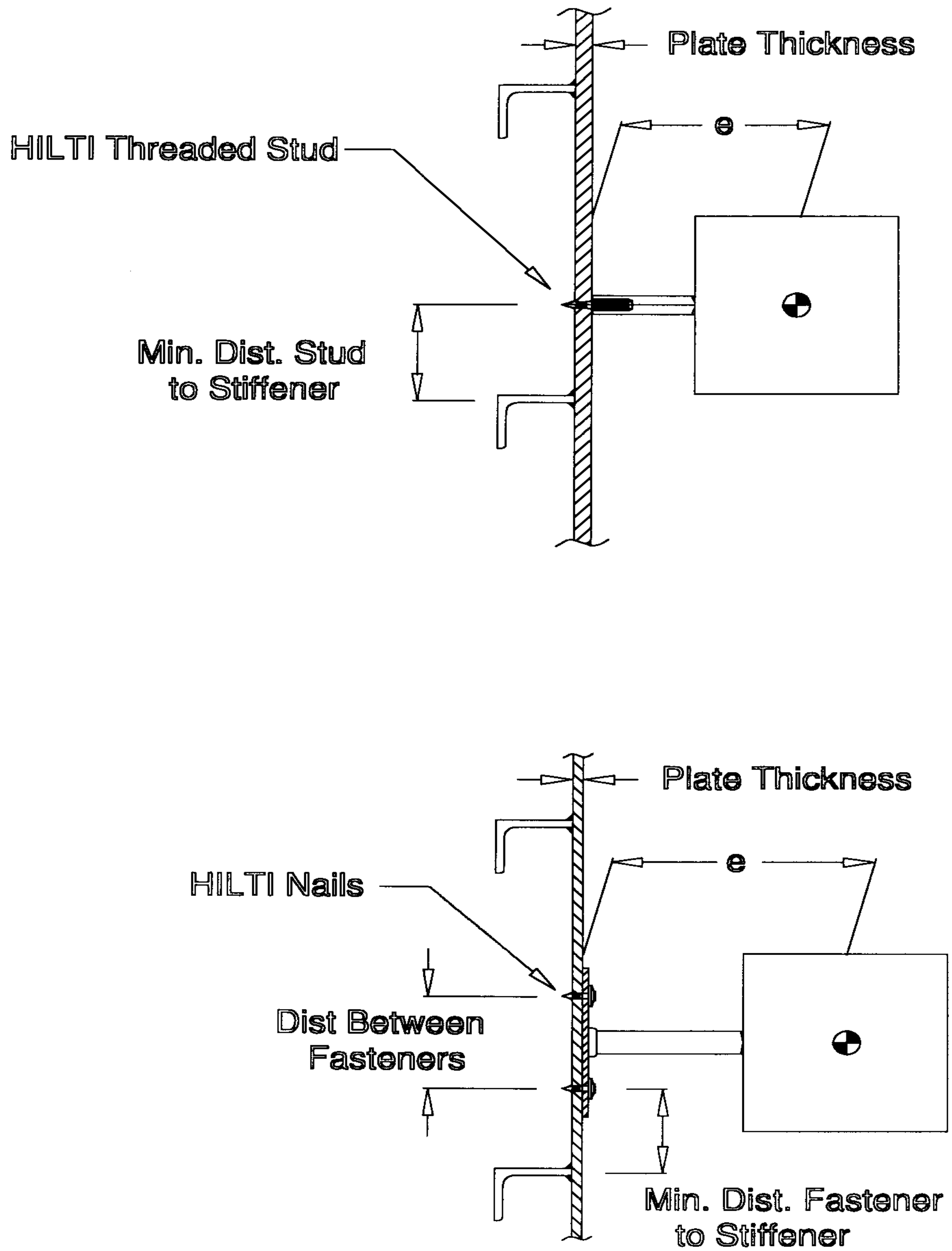


Plate Thickness
HILTI Threaded Stud
e
Min. Dist. Stud
to Stiffener
Plate Thickness
HILTI Nails
e
Dist Between
Fasteners
Min. Dist. Fastener
to Stiffener

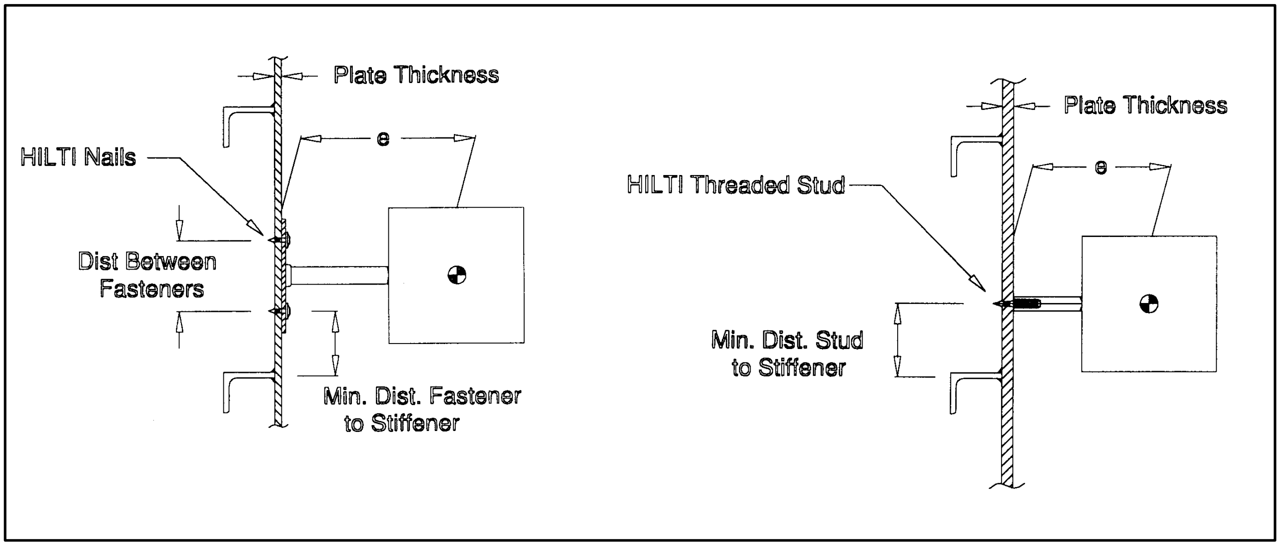
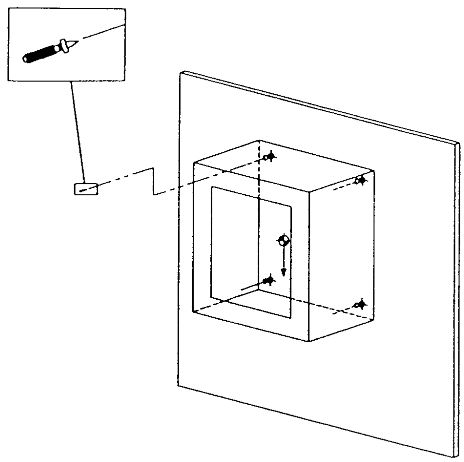
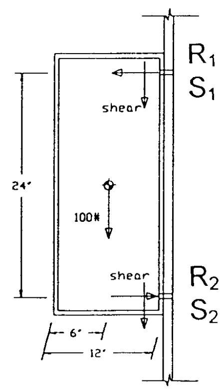


Plate Thickness
HILTI Nails
e
Dist Between Fasteners
Min. Dist. Fastener to Stiffener
Plate Thickness
HILTI Threaded Stud
e
Min. Dist. Stud to Stiffener





Tension :

$24" * R_1 = P * e$

$R_1 = (P * e) / 24"$

$R_1 = 100\# * 6" / 24"$

$R_1 = 25\#$

Shear :

$S_1 = S_2 = P / 4$

$S_1 = S_2 = 100\# / 4$

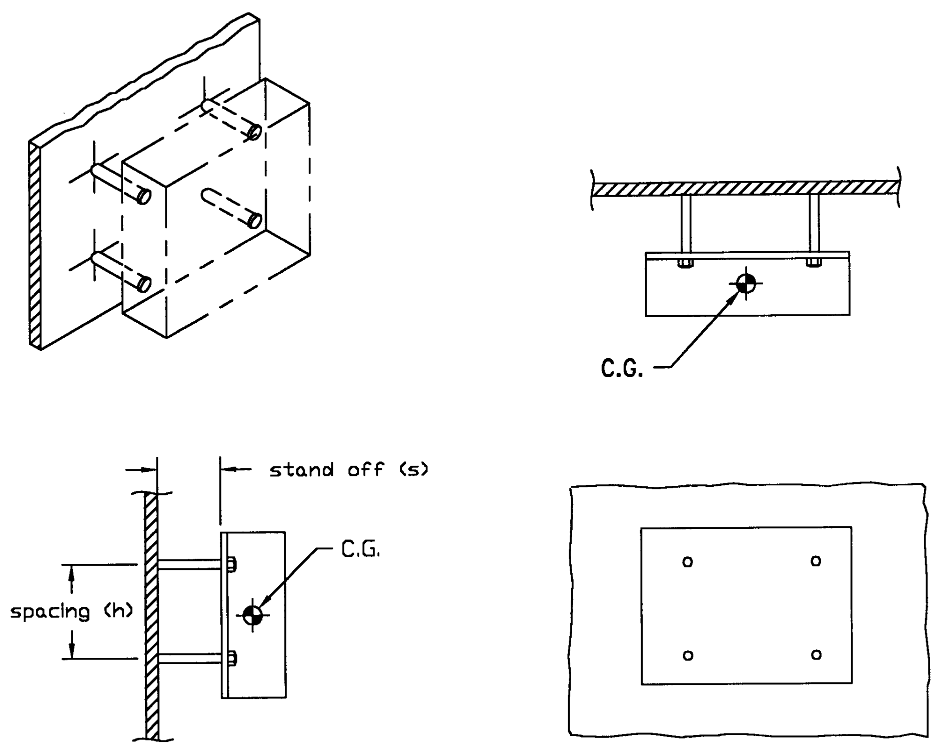
$S_1 = S_2 = 25\#$

Allowable Loads - 3/8" Threaded Stud

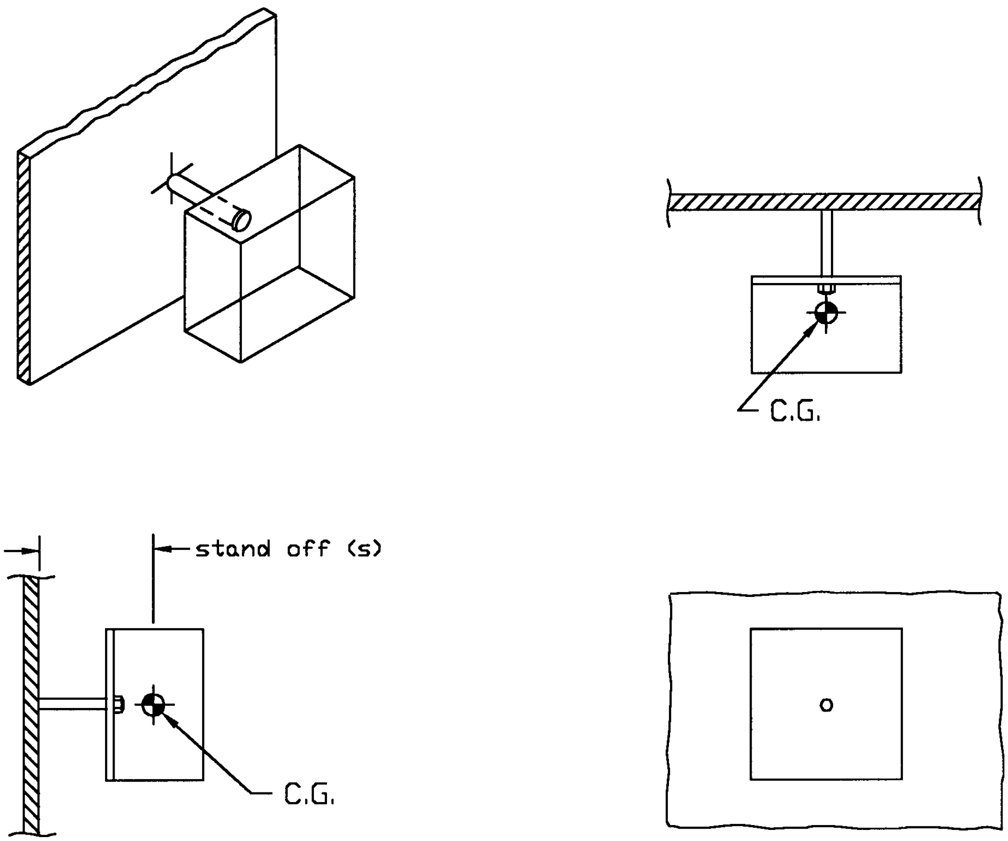
	Tension (lbs.)	Shear (lbs.)
From Hilti Technical Data : (Using Safety Factor of 5:1)	1150	1540
Shipboard Use : (Using Safety Factor of 2:1)	2875	3850
Load Factor :	2875 / 25 = 125	3850 / 25 = 154

APPENDIX D — STUD MOUNTED ATTACHMENT TECHNIQUES

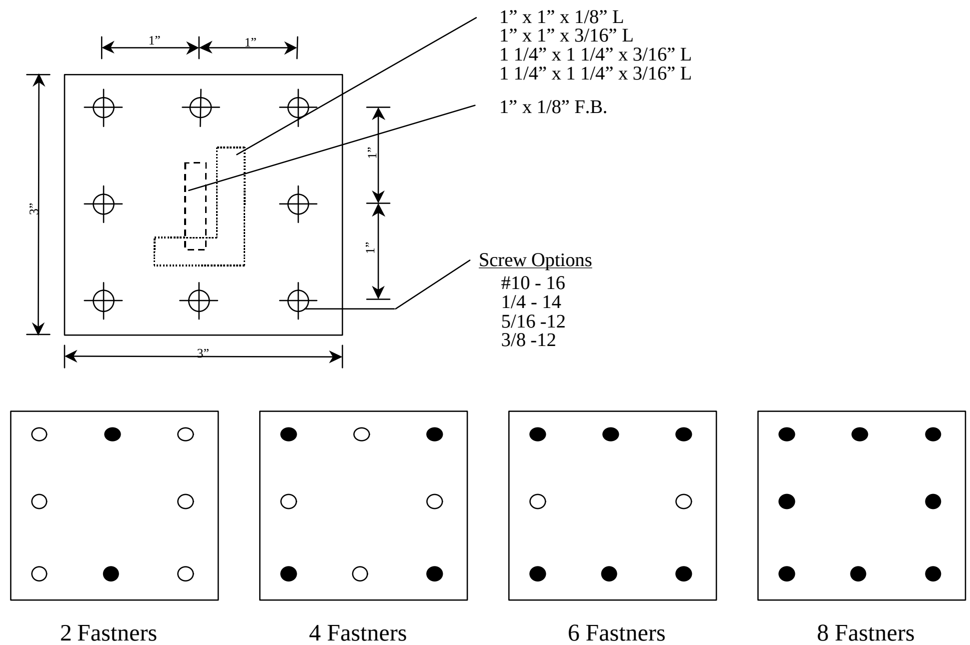
MUTIPLE STUDS



SINGLE STUD



Fastener and Pad Configurations



Note: Drawings not to scale.

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO.7 — ENGINEERING ANALYSIS AND DEVELOP STANDARDS

PRINCIPAL INVESTIGATOR:

DOMINIC BURNS
SENIOR ENGINEER
NATIONAL STEEL AND SHIPBUILDING COMPANY

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NEW ORLEANS, LA 70148

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF TABLES

7 ENGINEERING ANALYSIS AND DEVELOP STANDARDS

REFERENCES

1) Typical Ship Specification
2) AISC Steel Design Manual, Ninth Edition
3) Blodgett, "Design of Welded Steel Structures"
4) NASSCO Guidelines for Commercial Foundation Drawings, Section 11. 1
5) Bruhn, "Analysis and Design of Flight Vehicle Structures", p.D1.5-D1.6

INTRODUCTION

The grillage is the simplest and most common type of foundation. Therefore, where it is not possible to mount equipment with weld studs or spools, the greatest cost savings can be achieved by standardizing a producible grillage design. In the past, grillages have typically consisted of two or more parallel spans of angle iron welded continuously along their length to either deck or bulkhead plating or spanning between deck or bulkhead stiffeners. This is an inefficient method of installation because it typically involves a large amount of welding and fitting. Considering the number of grillages mounting light weight equipment aboard a ship, great cost savings can be achieved by instead lifting grillage angles up off of plating and stiffeners with chocks which attach the web of the angle to supporting ship structure. This practice reduces the amount of required welding and simplifies the foundation assembly.

Additional savings can be achieved if this grillage is then mounted directly to soft plating or cantilevered off of stiffeners, where these practices are feasible. Previous practice unnecessarily avoided landing on soft plate or cantilevering, and grillages were almost always bridged to rigid ship structure, even though this is typically not necessary with lighter equipments. By obviating this old convention, significant cost savings are generated by eliminating the pieces associated with bridging the foundation to ship structure. This greatly reduces the welding, cutting and fit-up time associated with a particular foundation.

The intention of this grillage study is to provide design guidance in terms of allowable equipment weight for grillages simply supported between chocks, cantilevered off of stiffeners and/or attached directly to soft plate. This guide is in the for m- of allowable weight curves where the allowable equipment weight is dependent on the length of span between chocks, the size of the angle used, the thickness of the ship plating and the ratio of the eccentricity of the equipment center of gravity to the distance between opposing bolts (e/h). So for a given piece of equipment and mounting location, the designer can choose the appropriate angle size based on the most producible mounting condition. Families of allowable curves were produced for both the simply supported chock mounted grillage and the cantilevered grillage using the following angle sizes: 2"×2"×3/16"; 2"×2"×1/4"; 2"×2"×3/8"; 2-1/2"×2-1/2"×3 /8"; 3"×3"×3/16"; 3"×3"×¼"; 3"×3"×3/8"; 3"×3"×1/2"; 4"×4"× 3/8" ; 4"×4"×½"; 4"×4"× ¾"; 6"×4×3/8" ; 6"×4"×½"; 6"×4"×¾". Another set of allowable curves was created for the landing of grillages on soft plate. This set of allowables is based on the thickness of the plate and provides guidance for plate thicknesses from 3/16" to 11/16".

METHOD OF ANALYSIS

Allowable weight for a given grillage configuration is determined based on a number of different failure criteria, all of which fall into two categories, strength criteria and frequency criteria. Spreadsheets were created which calculate the weight limits based on each criteria for a large envelope of grillage configurations. For each configuration, the lowest allowable weight from the most limiting criteria is used for that specific grillage. The allowables for each of these criteria is calculated using conservative methods, loads, and assumptions as outlined in the following.

GRILLAGE CONFIGURATIONS

Two different types of grillage configurations are considered in this study: grillages in which the spans are simply supported by chocks or structural stiffeners, and grillages where the angles are cantilevered off of ship structure. It is assumed that each of these two configurations consist of one or more sets of spans, where a span consists of two parallel pieces of angle. In reality a span may have more than two parallel angles, but in analysis it is conservative to use two to encompass all possibilities. For each configuration type, a worst case loading scenario is assumed which envelops all possible mountings on that grillage. That is, for the two grillage types, the load induced at an individual bolt and on the angle will be the highest load that any feasible configuration will produce.

SIMPLY SUPPORTED GRILLAGE CONFIGURATION

For the case of a grillage spanning between chocks or stiffeners, the worst condition will be the one which places a maximum bolt load on the middle of the angle. This case produces the maximum bending moment in the angle and the lowest natural frequency for the system. An example where this type of loading would occur would be a grillage supporting equipment with only two bolts, where the bolts land on the middle of the span (*see Figure 7-1 — Worst Simply Supported Grillage Configuration*). Another example would be a grillage supporting equipment with a narrow footprint; i.e. the bolts are very close together.

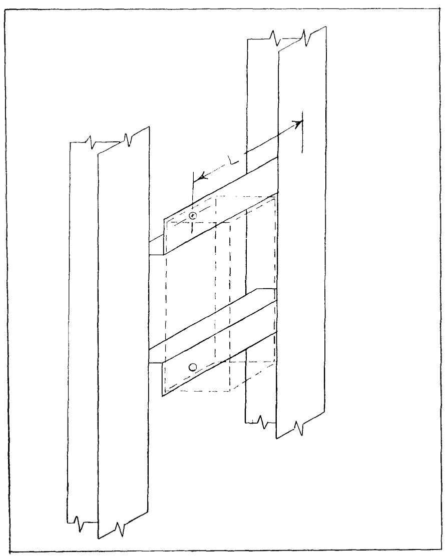


Figure 7-1 — Worst Simply Supported Grillage Configuration

CANTILEVER GRILLAGE CONFIGURATION

Similar to the simply supported grillage, the worst case for the cantilevered grillage is the one which produces the highest bending moment and lowest frequency. This is the condition where the equipment bolts land near the end of the cantilevered angles and the equipment itself does not support any moment. This will occur with equipments with narrow footprints, or bolting patterns in which only two of the bolts land on the cantilevered portion of the foundation (see *Figure 7-1 — Worst Cantilevered Grillage Configuration*).

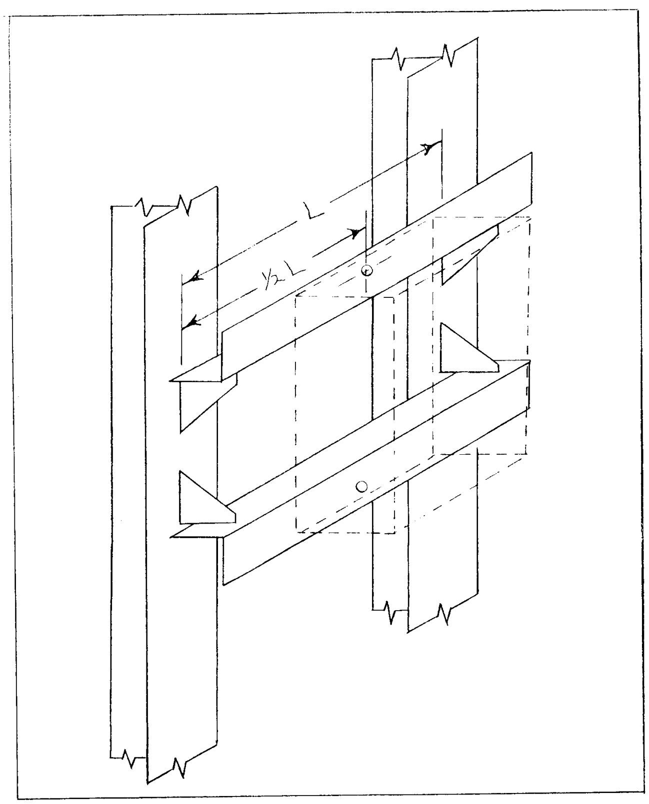


Figure 7-1 — Worst Cantilevered Grillage Configuration

LOADS

Loads are induced into grillage angles through the equipment bolts. Ship's motion loads on the equipment, measured in terms of equivalent static g's, are applied to the equipment and resultant forces are resolved at the bolts. Acceleration values, based on a worst case ship location, of 2.5 g's vertical, 1.25 g's transverse and 0.5 g's longitudinal are applied to the equipment simultaneously (see *Section 5, Appendix A* for calculations). Combined with the equipment weight, these accelerations produce forces on the equipment acting in all three directions. From this equipment load, forces are resolved on the grillage based on the assumed worst case configurations.

In calculating resultant forces the number of bolts on a span is not considered, instead a worst case assumption is made that each angle of a span has only two effective bolts. For example, axial and shear forces are computed as if there is only one bolt on either angle of a grillage span. Overturning forces are computed based on the e/h of the equipment and distributed on the grillage spans as if they are supported by only one bolt. Since forces are acting in three directions, there are two directions which produce overturning forces and in reality two different equipment e/h's to consider, but to be conservative the minimum of the two values, producing the higher resultant force for a given load, is used for both directions of overturning.

Additionally, the worst conceivable load at a bolt is calculated by orienting the grillage so that the ship's motion loads produce the highest bolt loads. For equipments with high e/h values, this is when the grillage and equipment are oriented such that the largest g's from vertical ship's motions produce overturning loads at the bolts. Grillages on a bulkhead have this type of overturning orientation. For equipments with low e/h values, the worst grillage orientation is when the equipment sits on the deck and the high vertical force acts perpendicular to the plane of the grillage, inducing axial bolt loads. *Figure 7-1 — Resolving of Grillage Forces* shows how the loads from a typical grillage orientation and bolt pattern are conservatively approximated.

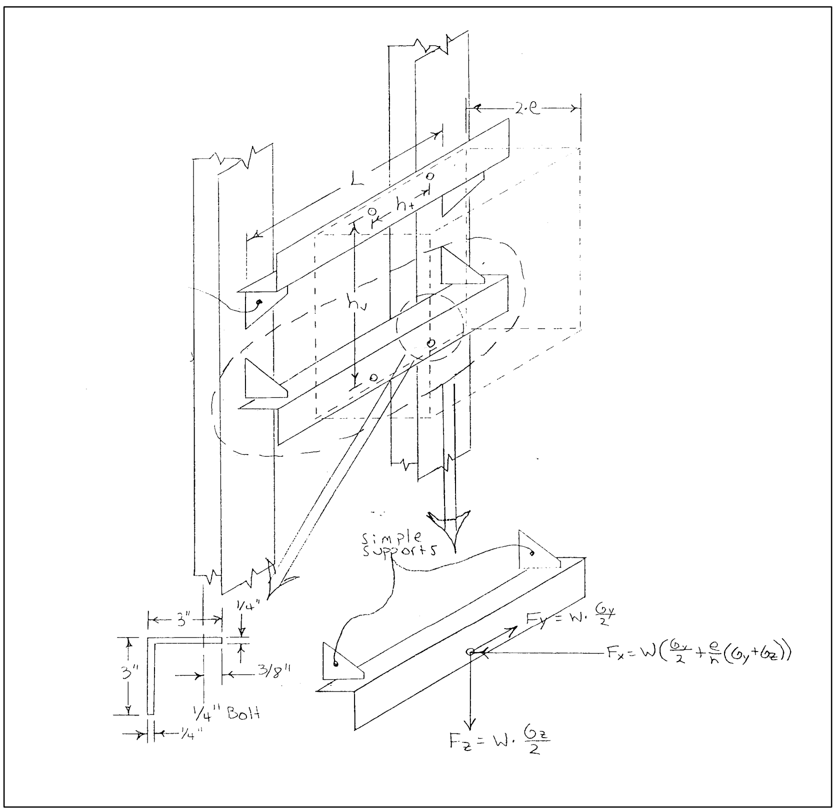


Figure 7-1 — Resolving of Grillage Forces

FAILURE CRITERIA

STRENGTH

Based on the above configurations and loads, stresses are computed for all possible failure modes. Failure is assumed to occur through yield failure in one or both of the angles, or by local yield failure in way of one or more bolts. All stresses are computed at their worst location, the spot on the grillage where the biggest force or moment occurs. The formulas used for computing different stresses are conservative, previously approved methods.

Angle stresses are calculated using beam formulas. Critical stress occurs in an angle as a result of both bending and axial loads in the beam. Bending stress is nominal, calculated based on the maximum moment and the elastic section modulus of the most extreme fibers. Bending stresses are combined for biaxial bending, where the stress at the toe of the angle from one direction of bending is added to the stress at the heel from the other direction of bending and vice-versa. This worst bending stress is then combined with the nominal axial stress calculated from the highest axial load in a grillage angle and the cross-sectional area of the angle. This maximum combined beam stress is the value used to check the integrity of the grillage angles.

Bolt attachment is checked for all modes of shear, bearing and bending. All calculations are performed assuming ¼" bolts, since this is the smallest bolt used by NASSCO (Reference 4), and smaller bolts produce higher stresses for all failure modes. Shear failure can either occur perpendicular to the angle flange due to axial bolt loads or parallel to the flange from shear loads in the bolt. Bearing stress is a nominal stress computed from the cross-sectional area of the bolt hole. Figure 4 shows all possible flange failure modes, and Appendix B provides the rationale for the calculation methods used in computing the nominal stresses.

Flange bending is the result of the moment created between the centerline of a bolt and the heel of the angle. The greater the bolt distance from the heel, the greater the flange bending moment. So to be conservative, the bolt is assumed to land at its furthest possible location from the heel, which according to NASSCO's Drafting Guide (Reference 4), is 3/8" from the toe of the angle for a ¼" bolt. The moment produced is resisted partially at the bolt and partially at the angle heel depending on the condition of fixity at those locations. Stresses are always critical at the location of the bolt since the effective section of the angle is much less in way of the point fixity at the bolt than along the line of fixity at the heel. Therefore, the conservative assumption is made that the equipment is always clamped to the flange at the bolt, and the amount of moment taken at the bolt is dependent on the condition of fixity at the heel. Curves are created for three cases of flange bending: partially free at the heel, fully fixed at the heel, and no flange bending possible. No flange bending possible is the case where the flange of the angle is prevented from bending by added structure, such as chocks which connect the flange directly to ship structure in way of the bolt. The remaining two cases distribute the moment on the flange differently. The fully fixed case places half the moment at the bolt and half at the heel, the partially fixed case puts eighty percent of the moment at the bolt and twenty percent at the heel. On a grillage this difference is the result of different fixities at the heel. For example, an angle with a chock welded to the heel of the angle in way of the bolt would be considered fully fixed, while an angle without the chock is considered to be partially fixed. The rationale for the calculation methods used appears in *Section 5, Appendix B* of this report.

FREQUENCY

An important criteria for all structure is the value of its natural frequency of vibration in relation to the frequency of any exciting forces on that structure. For grillages, it is therefore important to insure that the lowest natural frequency of vibration of the grillage is greater than the excitation frequency of the propeller. The natural frequency is checked for several modes of vibration, and the lowest natural frequency of the grillage is compared to the allowable frequency. These checks are made for the worst case grillage configurations described previously. Springs included in the natural frequency calculation for a grillage are the bending of the angle, in two directions, and the flexibility of the flange. Torsional flexibility of the angles is disregarded because of the assumption that the flange is clamped to the equipment, meaning that the moment normally taken torsionally by the angle is instead resisted by the equipment. These two springs are coupled in series to determine the stiffness and subsequent natural frequency of the grillage for three different vibration modes. Natural frequency is

calculated for vibration of the grillage parallel to its plane, perpendicular to its plane and due to overturning motion of the equipment. The mode which results in the lowest natural frequency is the one which governs the acceptability of the grillage.

When a grillage does not land on rigid ship structure, such as stiffeners or back up structure, it is necessary to check the natural frequency of the grillage coupled with the vibration of the soft plate. However it is no longer necessary to include the angle as a spring in this calculation because when a grillage is landed on soft plate the corner bolts of the equipment fall at the extreme ends of the grillage in way of the chocks. The springs for this natural frequency calculation are thus the flange flexibility and the out-of-plane soft plate bending. Natural frequency is calculated based on these series springs for the perpendicular and overturning modes of vibration.

ALLOWABLES

STRESS

Maximum allowable stress for any failure mode is set at a value which precludes yielding of the angle. Considering that the loading and orientation of the grillage and bolting are very conservative, the material allowable is taken as eighty percent (80%) of the 0.2 material static yield strength. This is the allowable for nominal tensile stress. For nominal shear and bearing stress, a percentage reduction is taken on the tensile allowable to reflect steel's capacity for carrying those types of loads. Shear is taken as sixty percent of the tensile allowable and the bearing allowable is set at eighty percent of the tensile allowable. Given that the foundations for the Sealift ships are to be constructed of mild steel with a yield strength of thirty-four thousand psi (34 ksi), the allowable tensile stress is 27.2 ksi, the allowable shear stress is 16.32 ksi, and the allowable bearing stress is 21.76 ksi.

FREQUENCY

Based on the propeller rpm and number of blades of the Sealift new construction ships, the allowable natural frequency for a grillage is twelve Hertz (12 Hz). This frequency is 1.25 times the excitation frequency of the propeller. It must be insured that the natural frequency of any grillage, be it coupled with soft plate or not, is equal to or greater than this number.

RESULTS

The results of this study is a collection of graphs and tables which provide the allowable weight on a grillage span based on the type of grillage (simply supported or cantilevered), angle size, length of unsupported span, e/h of the equipment, type of flange bending and thickness of soft plate, where applicable. These tables and graphs were created by performing tabular calculations on all the different grillage configurations. These calculations were performed using the assumptions, techniques, and allowables described in the above sections. A sample of these spreadsheet calculations outlining the specific formulas and methods of analysis appears in *Section 5, Appendix C*.

SIMPLY SUPPORTED AND CANTILEVERED GRILLAGE RESULTS

For simply supported and cantilevered grillages, a different graph is generated for each flange bending condition and e/h value studied. The flange bending conditions are no bolt chocks (partially fixed at the heel), bolt chocks (fully fixed at the heel), and no flange bending possible (the flange is restrained from bending). Three different e/h values are examined: e/h equals 1.5, 1.0, and 0.5. Since there are two variables each with three possibilities, there are a total of nine graphs for both the simply supported and cantilevered conditions, or a grand total of eighteen graphs. Each graph plots the length of unsupported span versus the allowable equipment weight for that length of span. The length of span for a simply supported grillage is the distance between adjacent chocks which lift a grillage angle up off of ship structure or the

distance between stiffeners to which the grillage angles are welded. For a cantilevered grillage, the length of unsupported span is the distance from the support of the cantilevered angle to the bolt furthest out on the angle. A different curve is plotted for the following fourteen angle sizes studied:

2"×2"×3/16"	2"×2"×1/4"	2"×2"×3/8"	2-1/2”×2-1/2”×3/8”	3”×3”×3/16”	3”×3”×1/4”
3”×3”×3/8”	3”×3”×1/2”	4”×4”×3/8”	4”×4”×1/2”	4”×4”×3/4”	6”×4”×3/8”
6”×4”×1/2”	6”×4”×3/4”				

Thus, these eighteen graphs encompass a large envelope of grillage possibilities and provide allowables which encompass all potential failure modes. These graphs and supporting tables follow in the sections labeled *Simply Supported Grillage Results* and *Cantilevered Grillage Results*.

SOFT PLATE RESULTS

A different set of curves was developed for allowable equipment weights based on landing grillages on soft plate. Similar to the curves for landing on ship structure, a different curve is developed for each angle size. However the allowable is based on the thickness of the plate, instead of the length of the span. Calculations were performed for plate thicknesses from 3 /16" to "1,611 at '/,601 increments. There are a total of nine plots, one for each e/h and flange bending condition examined. These graphs and supporting tables follow in the section labeled *Soft Plate Results*.

SIMPLY SUPPORTED GRILLAGE RESULTS

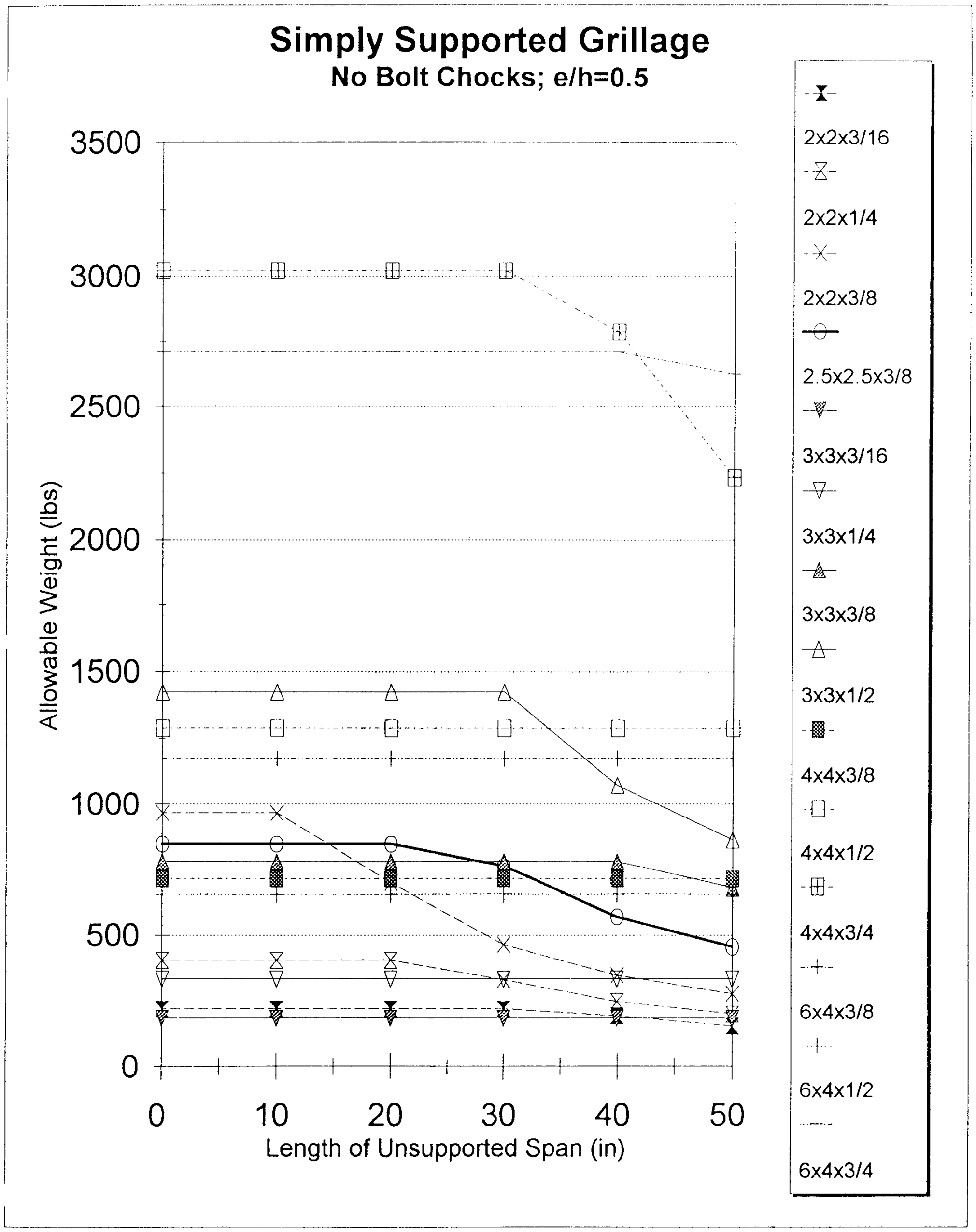


Figure 7-1 — Simply Supported Grillage, No Bolt Chocks; e/h = 0.5

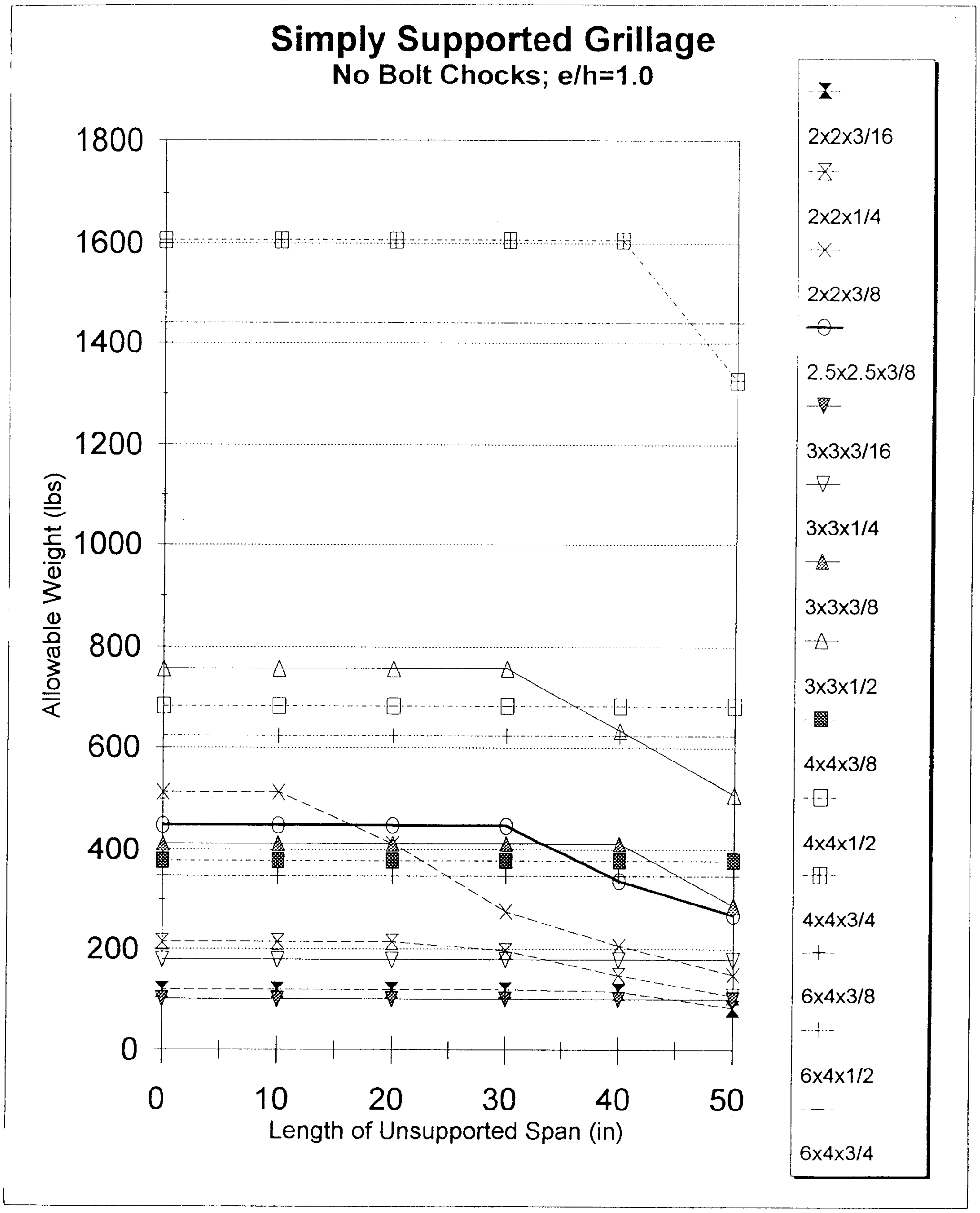


Figure 7-2 — Simply Supported Grillage, No Bolt Chocks; e/h = 1.0

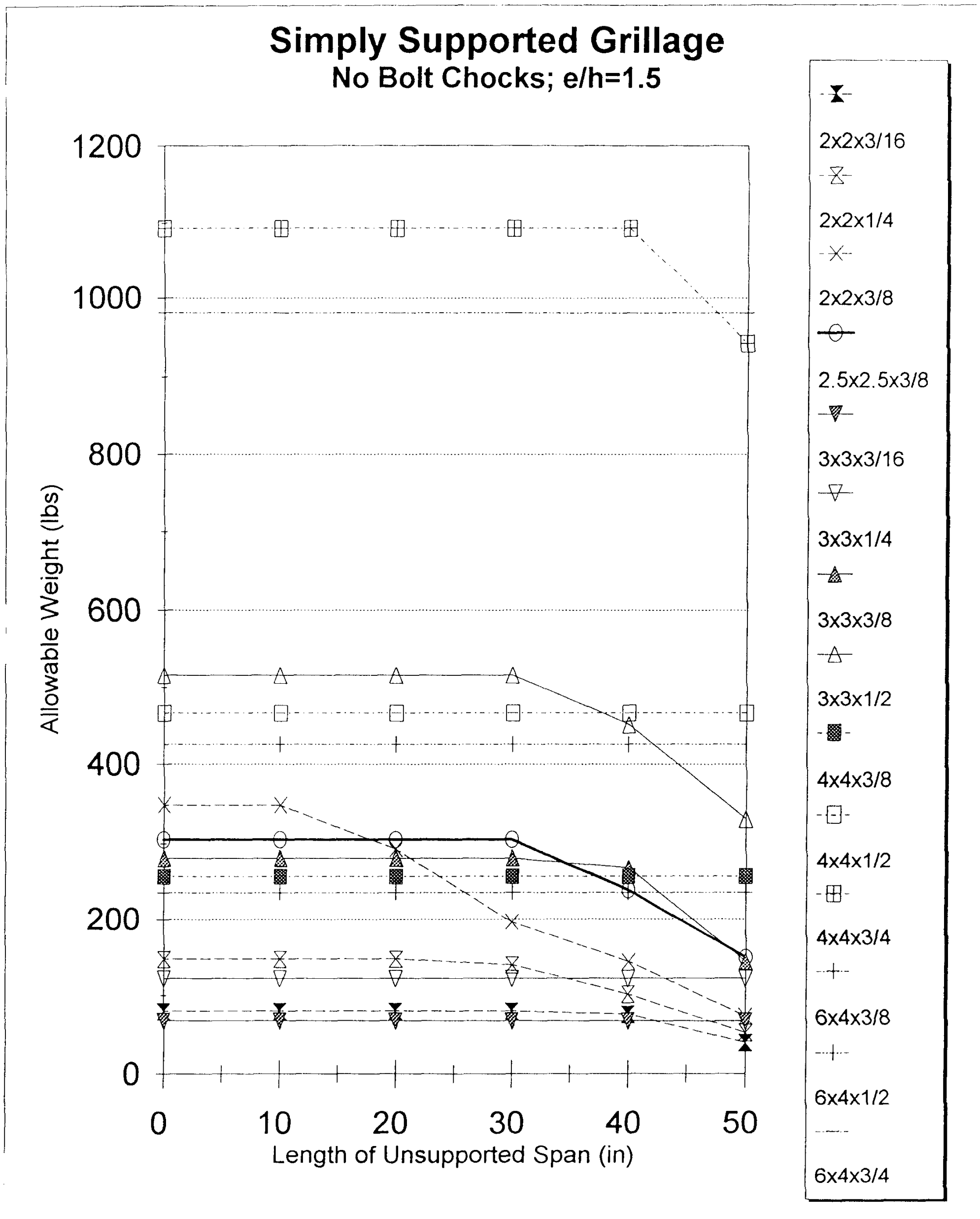


Figure 7-3 — Simply Supported Grillage, No Bolt Chocks; e/h = 1.5

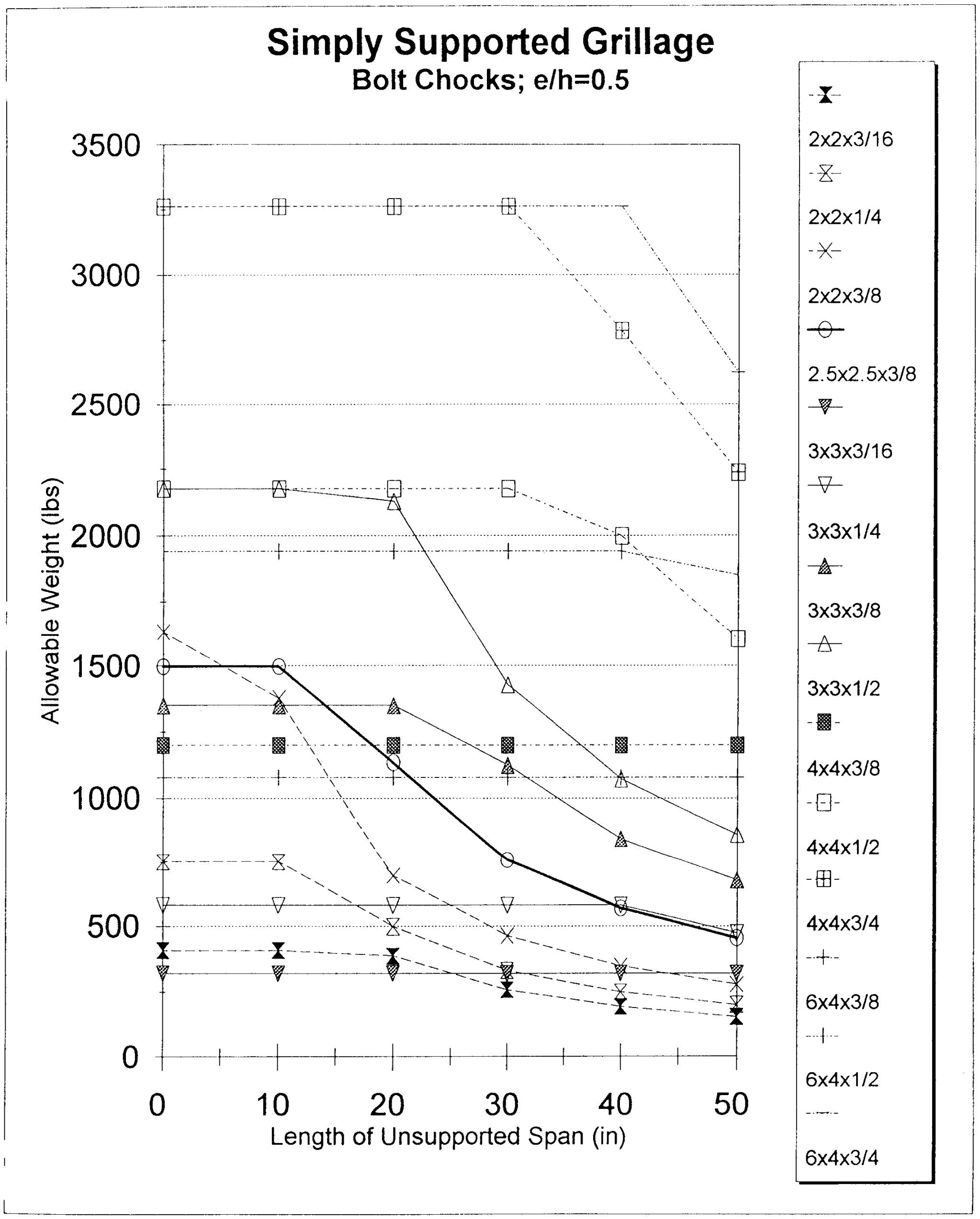


Figure 7-4 — Simply Supported Grillage, Bolt Chocks; e/h = 0.5

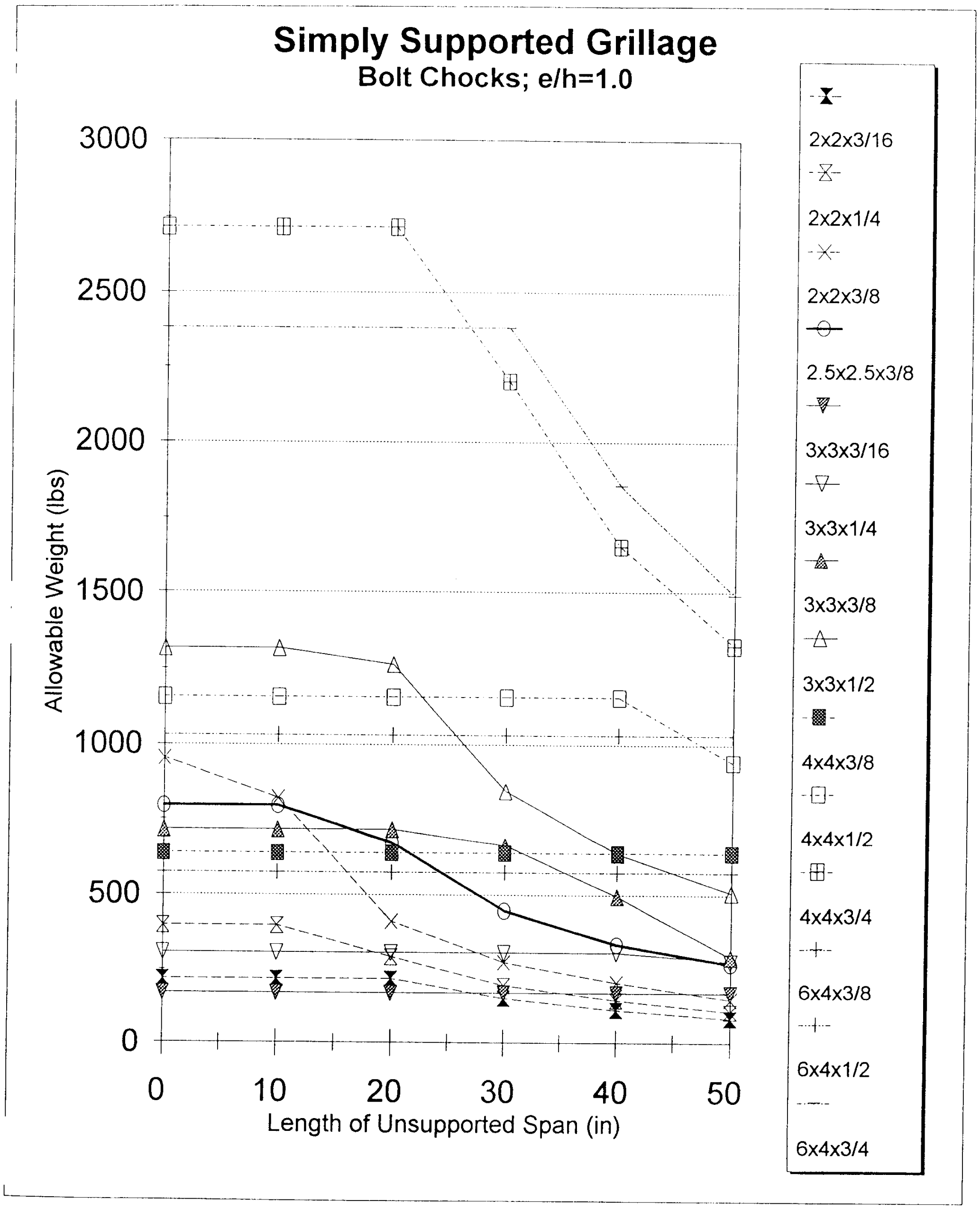


Figure 7-5 —Simply Supported Grillage, Bolt Chocks; e/h = 1.0

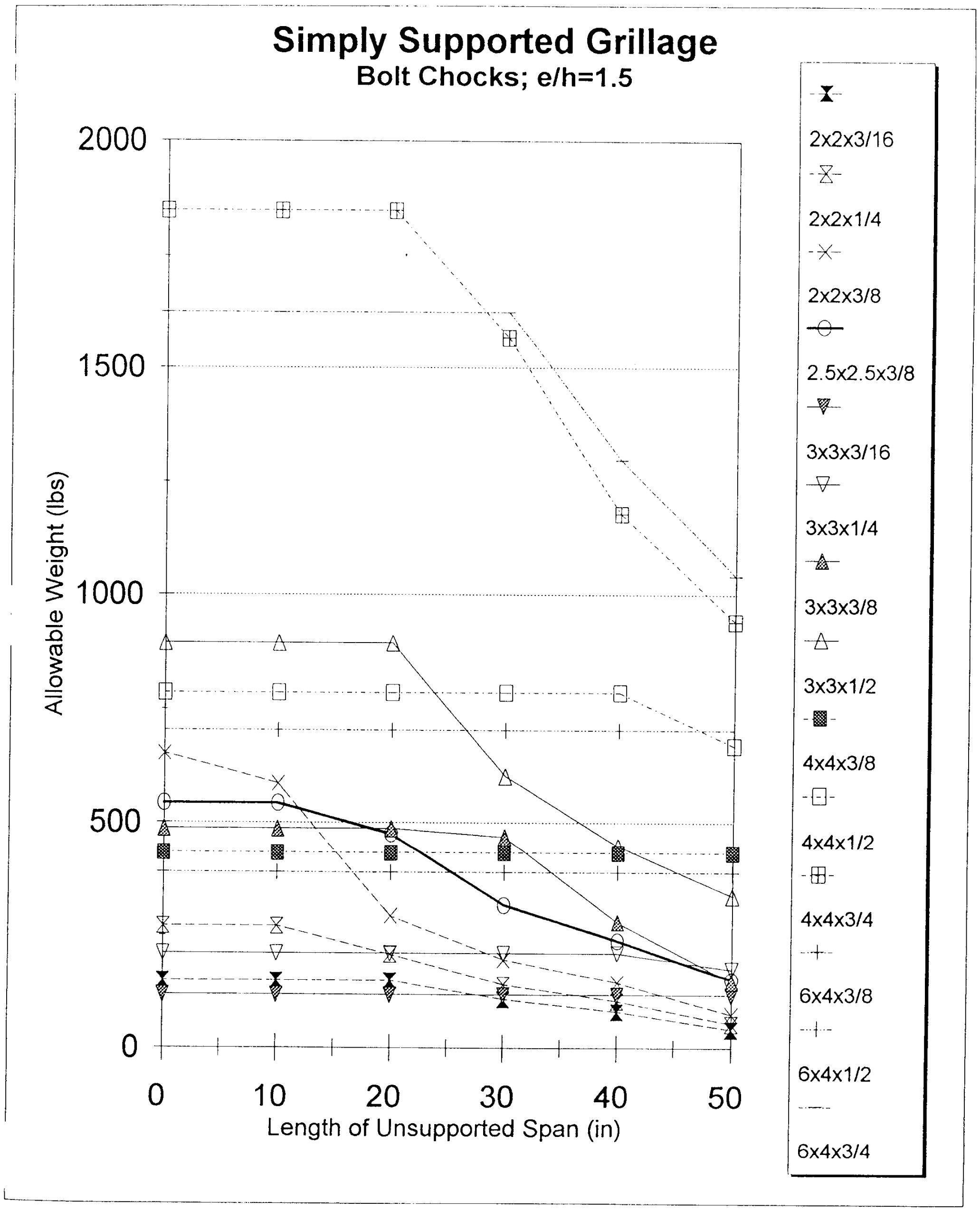


Figure 7-6 — Simply Supported Grillage, Bolt Chocks; e/h = 1.5

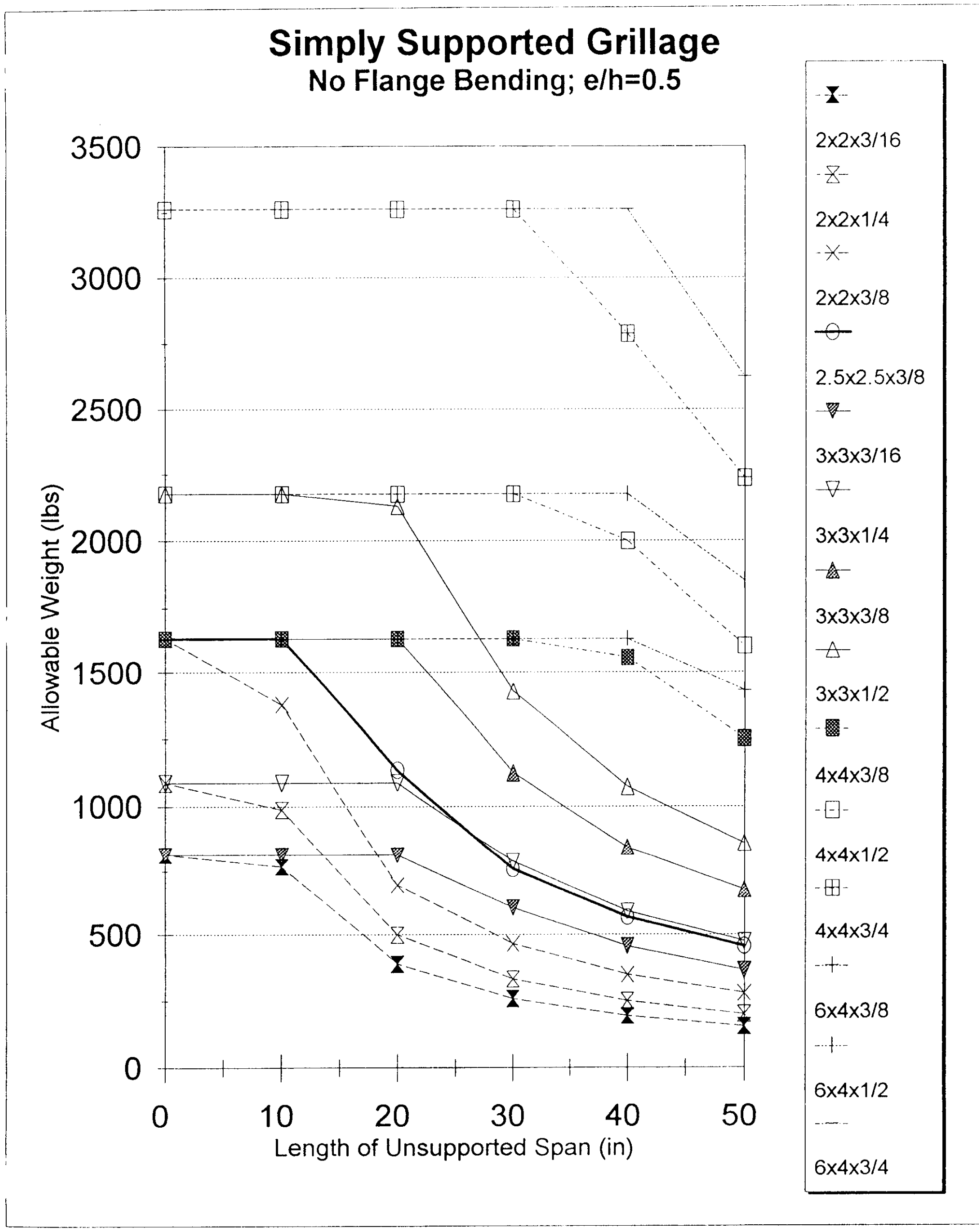


Figure 7-7 — Simply Supported Grillage, No Flange Bending; e/h = 0.5

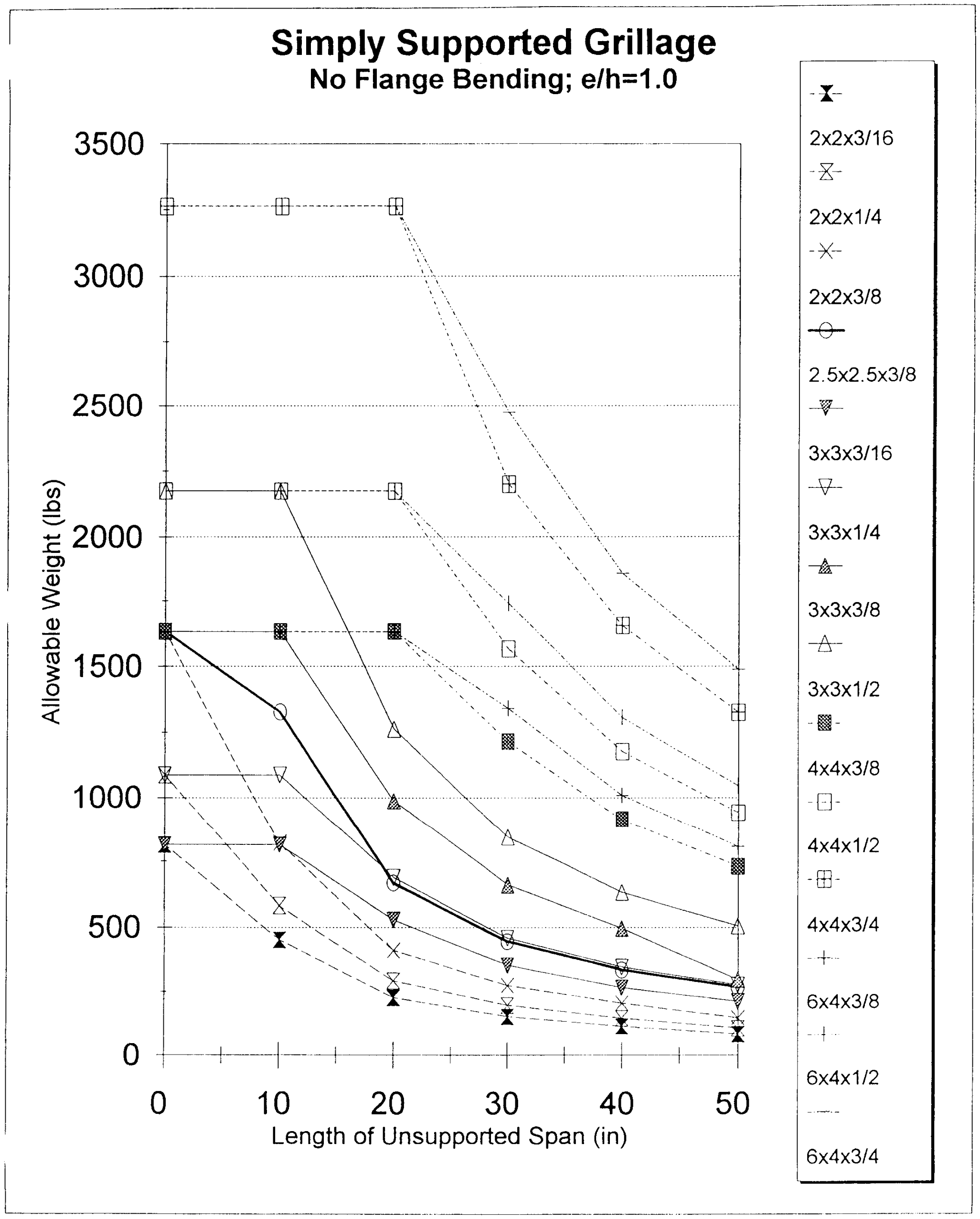


Figure 7-8 — Simply Supported Grillage, No Flange Bending; e/h = 1.0

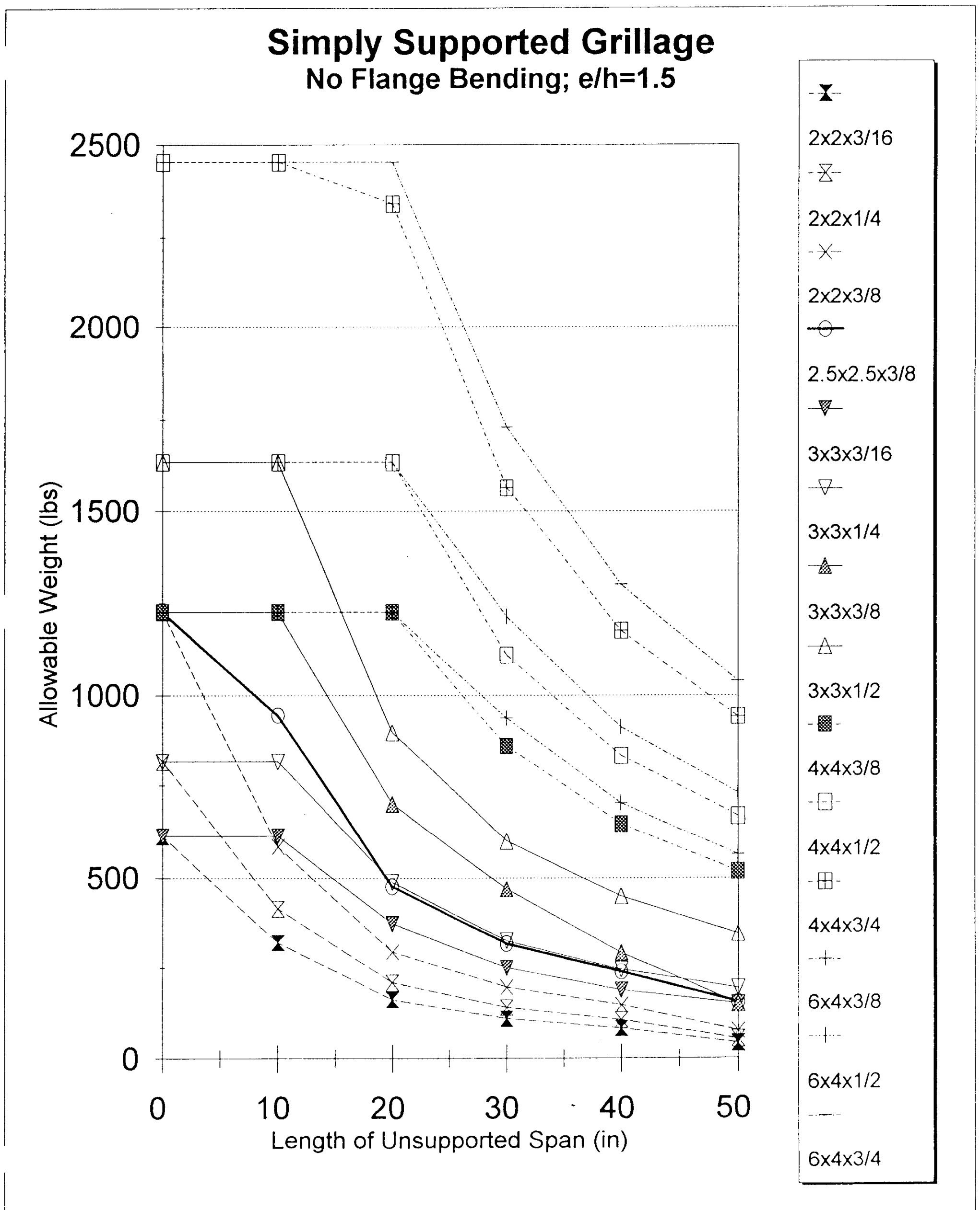


Figure 7-9 — Simply Supported Grillage, No Flange Bending; e/h = 1.5

ALLOWABLE GRILLAGE WEIGHTS — GRILLAGE WITH SIMPLY SUPPORTED SPANS — NO BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	224	119	81	408	217	147	966	513	350	845	449	306
20	224	119	81	408	217	147	697	414	294	845	449	306
30	224	119	81	335	197	139	467	277	197	760	449	306
40	196	115	77	252	148	102	351	208	144	572	337	239
50	157	82	41	202	107	53	281	149	74	458	270	149

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	224	119	81	408	217	147	966	513	350	845	449	306
20	224	119	81	408	217	147	697	414	294	845	449	306
30	224	119	81	335	197	139	467	277	197	760	449	306
40	196	115	77	252	148	102	351	208	144	572	337	239
50	157	82	41	202	107	53	281	149	74	458	270	149

	4×4×3/8			4×4×½			4×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	711	378	257	1290	685	466	3024	1606	1094
10	711	378	257	1290	685	466	3024	1606	1094
20	711	378	257	1290	685	466	3024	1606	1094
30	711	378	257	1290	685	466	3024	1606	1094
40	711	378	257	1290	685	466	2789	1606	1094
50	711	378	257	1290	685	466	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	654	347	236	1176	625	425	2713	1441	981
10	654	347	236	1176	625	425	2713	1441	981
20	654	347	236	1176	625	425	2713	1441	981
30	654	347	236	1176	625	425	2713	1441	981
40	654	347	236	1176	625	425	2713	1441	981
50	654	347	236	1176	625	425	2626	1441	981

Allowable Grillage WEIGHTS — Grillage With Simply SuppoRTED Spans — Bolt Chocks (Allowable Weight in Lbs.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	411	219	149	753	400	272	1632	956	651	1500	797	543
10	411	219	149	753	400	272	1378	822	586	1500	797	543
20	390	219	149	500	295	209	697	414	294	1135	671	476
30	261	153	108	335	197	139	467	277	197	760	449	318
40	196	115	80	252	148	104	351	208	145	572	337	239
50	157	84	42	202	108	54	281	149	75	458	270	152

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	322	171	117	582	309	210	1350	717	488	2176	1316	896
10	322	171	117	582	309	210	1350	717	488	2176	1316	896
20	322	171	117	582	309	210	1350	717	488	2130	1264	896
30	322	171	117	582	309	210	1126	663	470	1429	846	601
40	322	171	117	582	309	210	847	498	281	1075	635	451
50	322	171	117	477	278	176	679	295	147	861	509	339

	4×4×3/8			4×4×½			4×4×¾		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1200	638	434	2176	1157	788	3264	2720	1852
10	1200	638	434	2176	1157	788	3264	2720	1852
20	1200	638	434	2176	1157	788	3264	2720	1852
30	1200	638	434	2176	1157	788	3264	2203	1567
40	1200	638	434	2002	1157	788	2789	1656	1177
50	1200	638	434	1605	944	669	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1080	574	391	1944	1033	703	3264	2384	1623
10	1080	574	391	1944	1033	703	3264	2384	1623
20	1080	574	391	1944	1033	703	3264	2384	1623
30	1080	574	391	1944	1033	703	3264	2384	1623
40	1080	574	391	1944	1033	703	3264	1861	1300
50	1080	574	391	1853	1033	703	2626	1491	1041

Allowable Grillage WEIGHTS — Grillage With Simply SuppoRTED Spans — no flange bending (Allowable Weight in Lbs.)

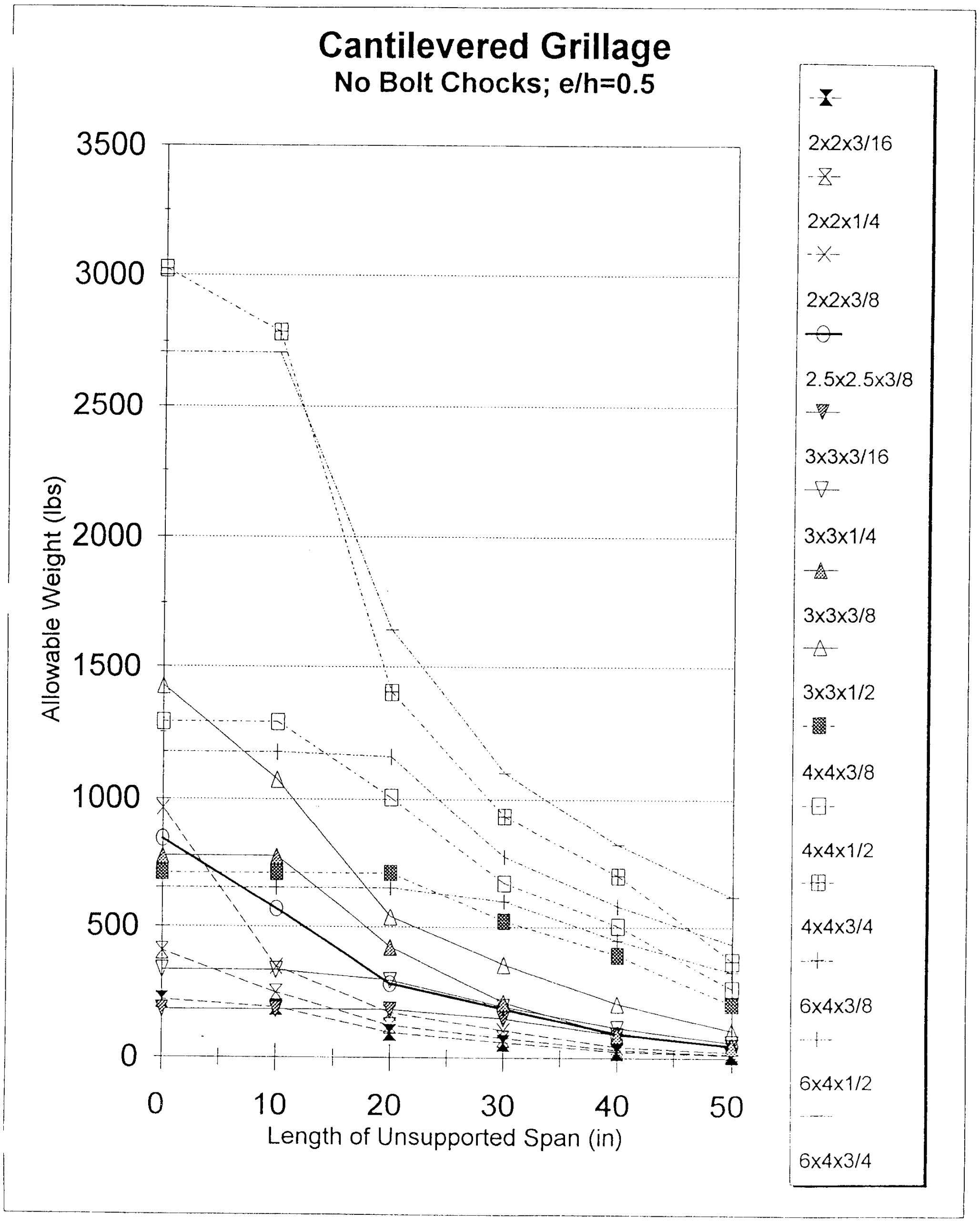
	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	770	454	322	989	585	415	1378	822	586	1632	1330	947
20	390	229	162	500	295	209	697	414	294	1135	671	476
30	261	153	108	335	197	139	467	277	197	760	449	318
40	196	115	81	252	148	105	351	208	146	572	337	239
50	157	85	43	202	109	54	281	150	75	458	270	154

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
20	816	531	375	1088	691	489	1632	991	703	2130	1264	899
30	609	355	251	790	463	327	1126	663	470	1429	846	601
40	458	267	188	595	348	246	847	498	294	1075	635	451
50	367	214	150	477	278	195	679	301	150	861	509	347

	4×4×3/8			4×4×½			4×4×¾		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1632	1227	2176	2176	1636	3264	3264	2454
20	1632	1632	1227	2176	2176	1636	3264	3264	2343
30	1632	1216	861	2176	1567	1111	3264	2203	1567
40	1560	914	647	2002	1178	835	2789	1656	1177
50	1251	733	518	1605	944	669	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1632	1227	2176	2176	1636	3264	3264	2454
20	1632	1632	1227	2176	2176	1636	3264	3264	2454
30	1632	1344	838	2176	1741	1216	3264	2476	1730
40	1632	1010	704	2176	1309	913	3264	1861	1300
50	1432	809	564	1853	1048	731	2626	1491	1041

CANTILEVERED GRILLAGE RESULTS


Cantilevered Grillage
No Bolt Chocks; e/h=0.5
3500
3000
2500
2000
1500
1000
500
0
Allowable Weight (lbs)
0
10
20
30
40
50
Length of Unsupported Span (in)
2x2x3/16
2x2x1/4
2x2x3/8
2.5x2.5x3/8
3x3x3/16
3x3x1/4
3x3x3/8
3x3x1/2
4x4x3/8
4x4x1/2
4x4x3/4
6x4x3/8
6x4x1/2
6x4x3/4

Figure

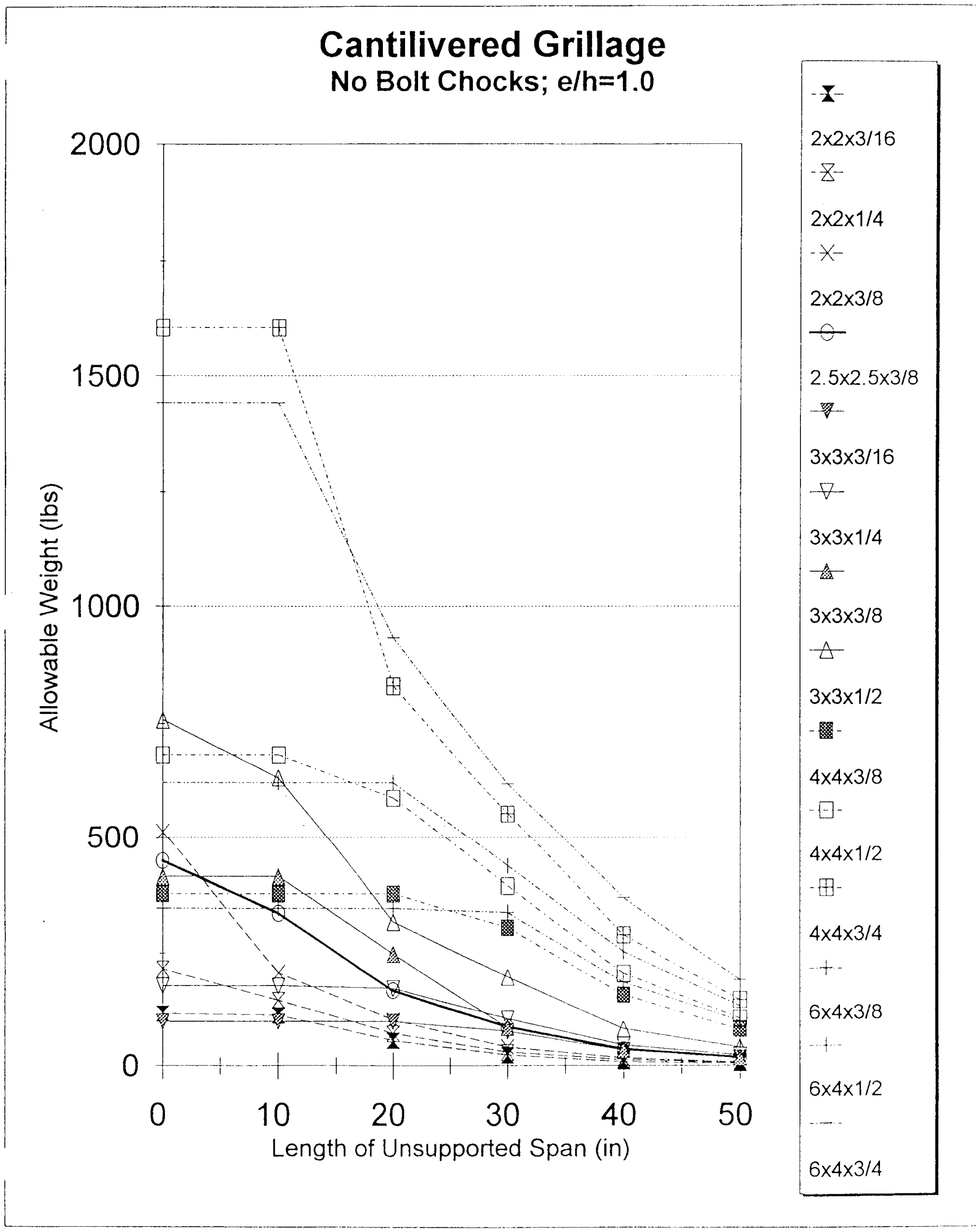


Figure 7-11 — Cantelevered Grillage, No Bolt Chocks;   e/h = 1.0

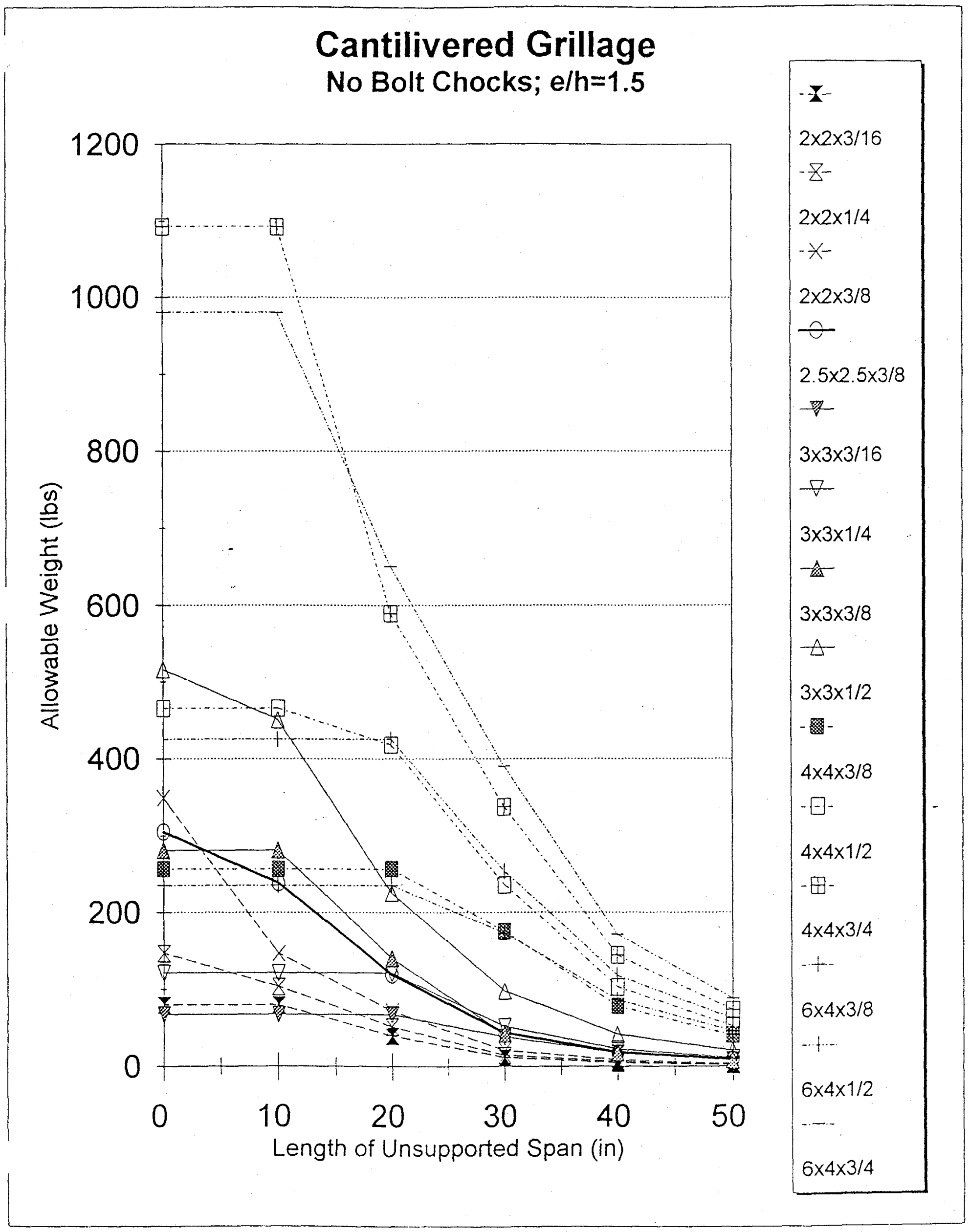


Figure 7-12 — Cantelevered Grillage, No Bolt Chocks; e/h = 1.5

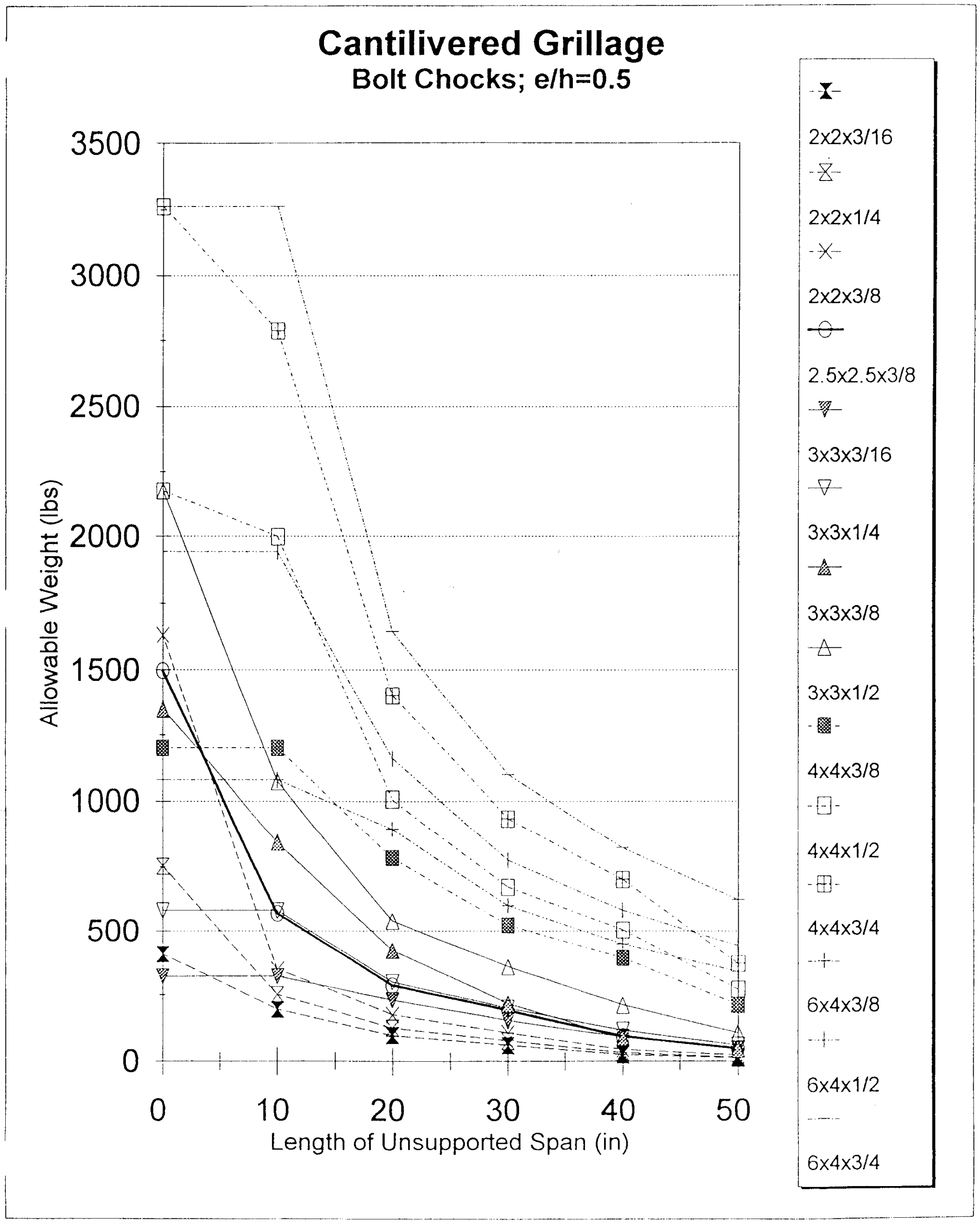


Figure 7-13 — Cantelevered Grillage, Bolt Chocks; e/h = 0.5

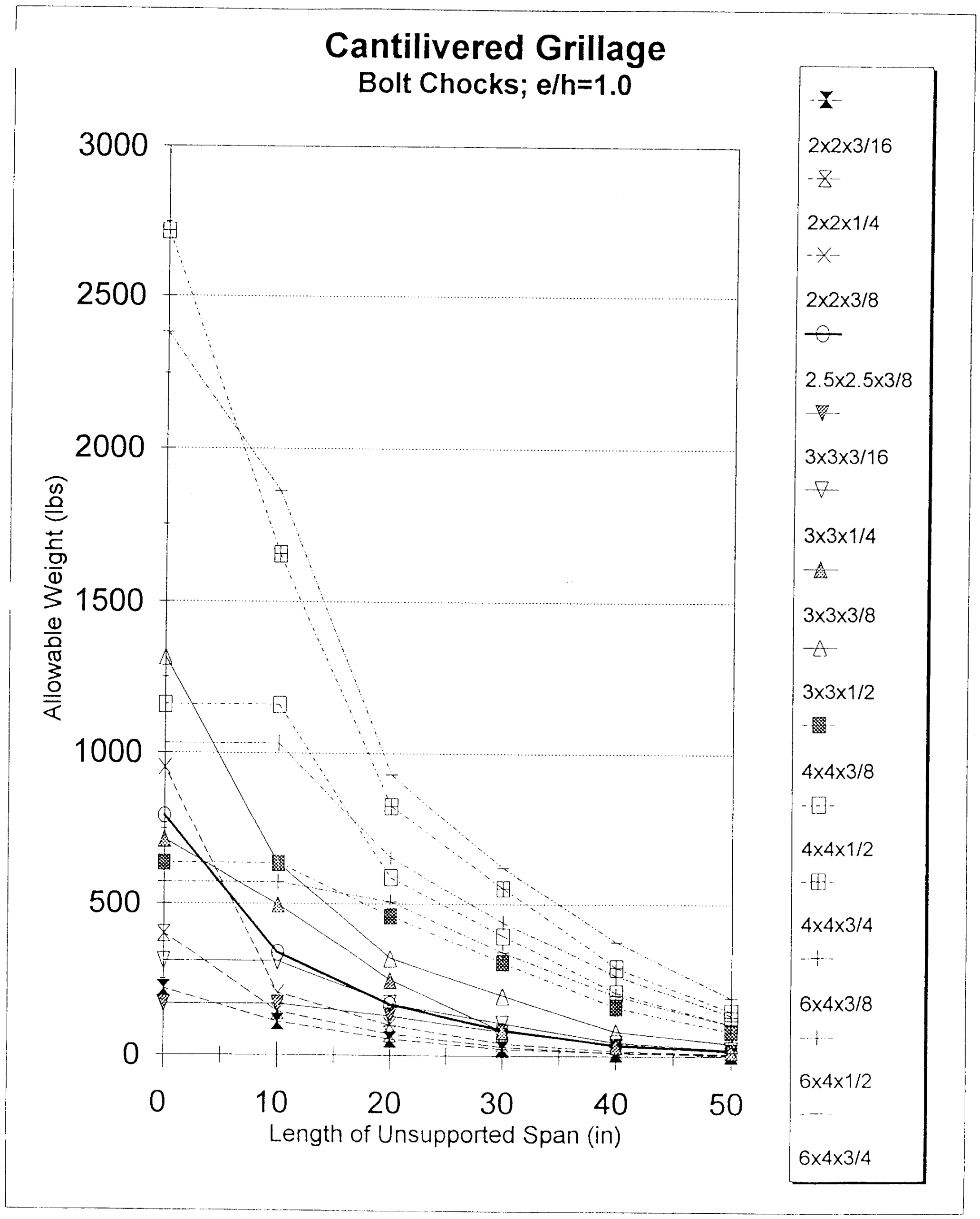


Figure 7-14 — Cantelevered Grillage, Bolt Chocks; e/h = 1.0

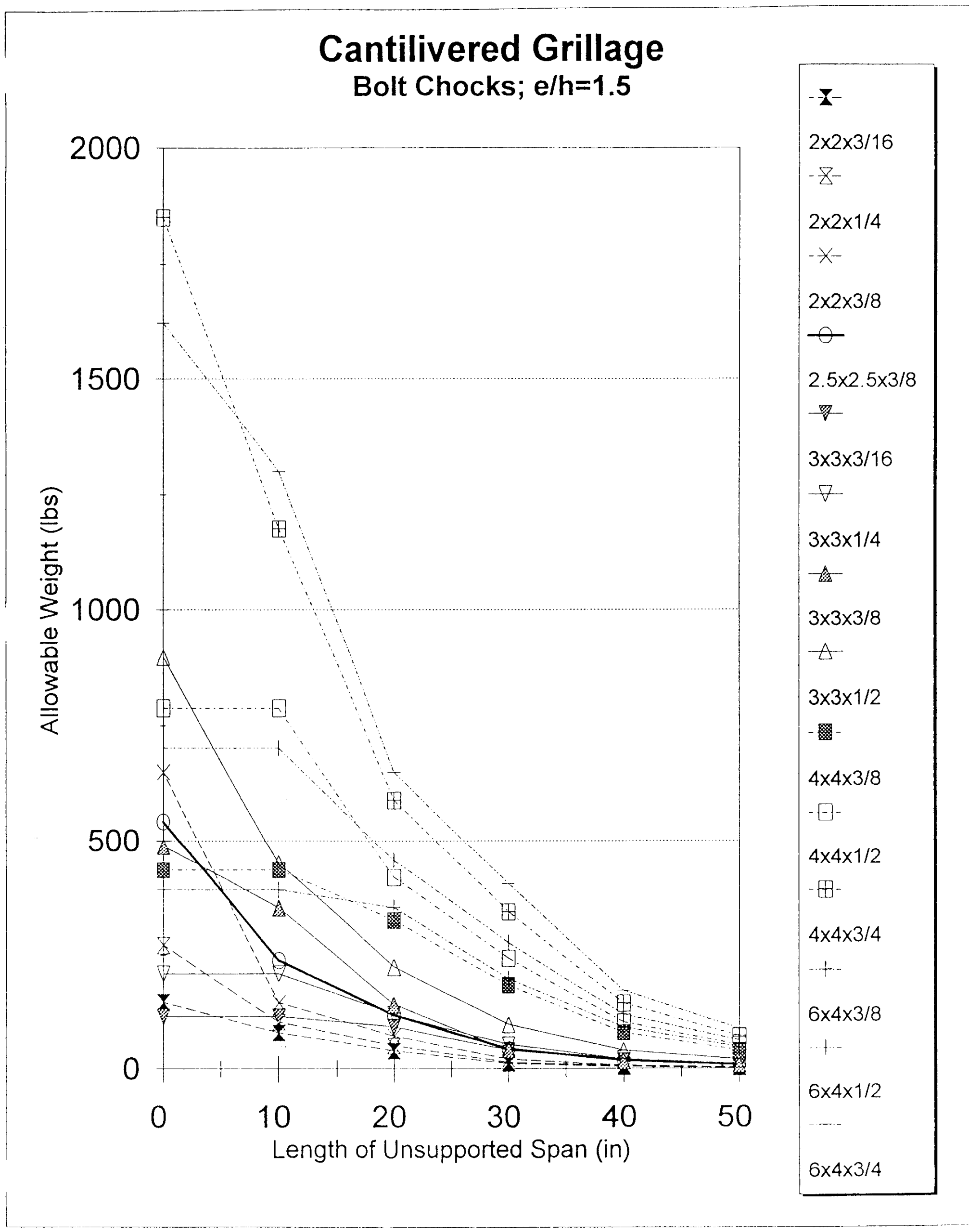


Figure 7-15 — Cantelevered Grillage, Bolt Chocks; e/h = 1.5

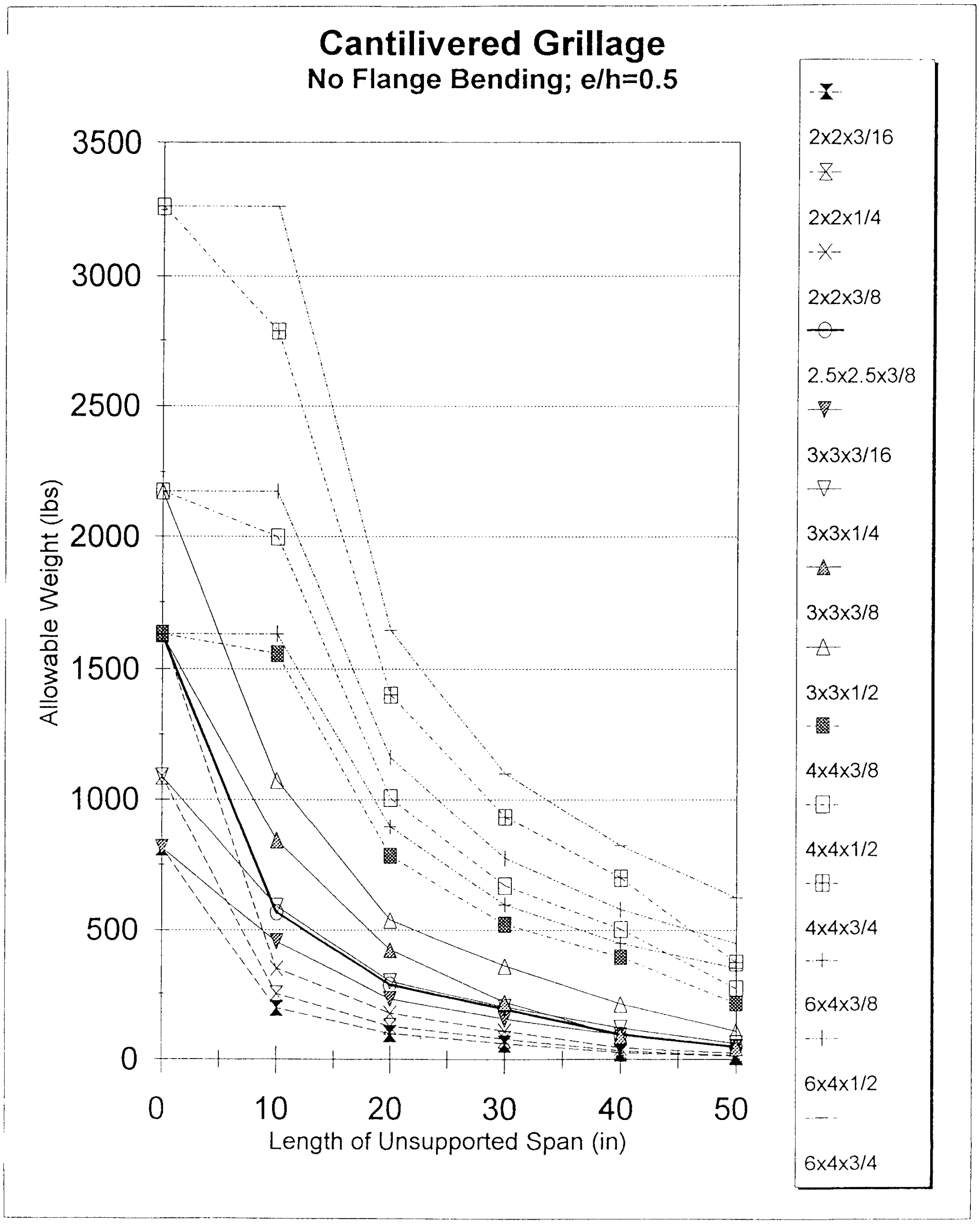


Figure 7-16 — Cantelevered Grillage, No Flange Bending; e/h = 0.5

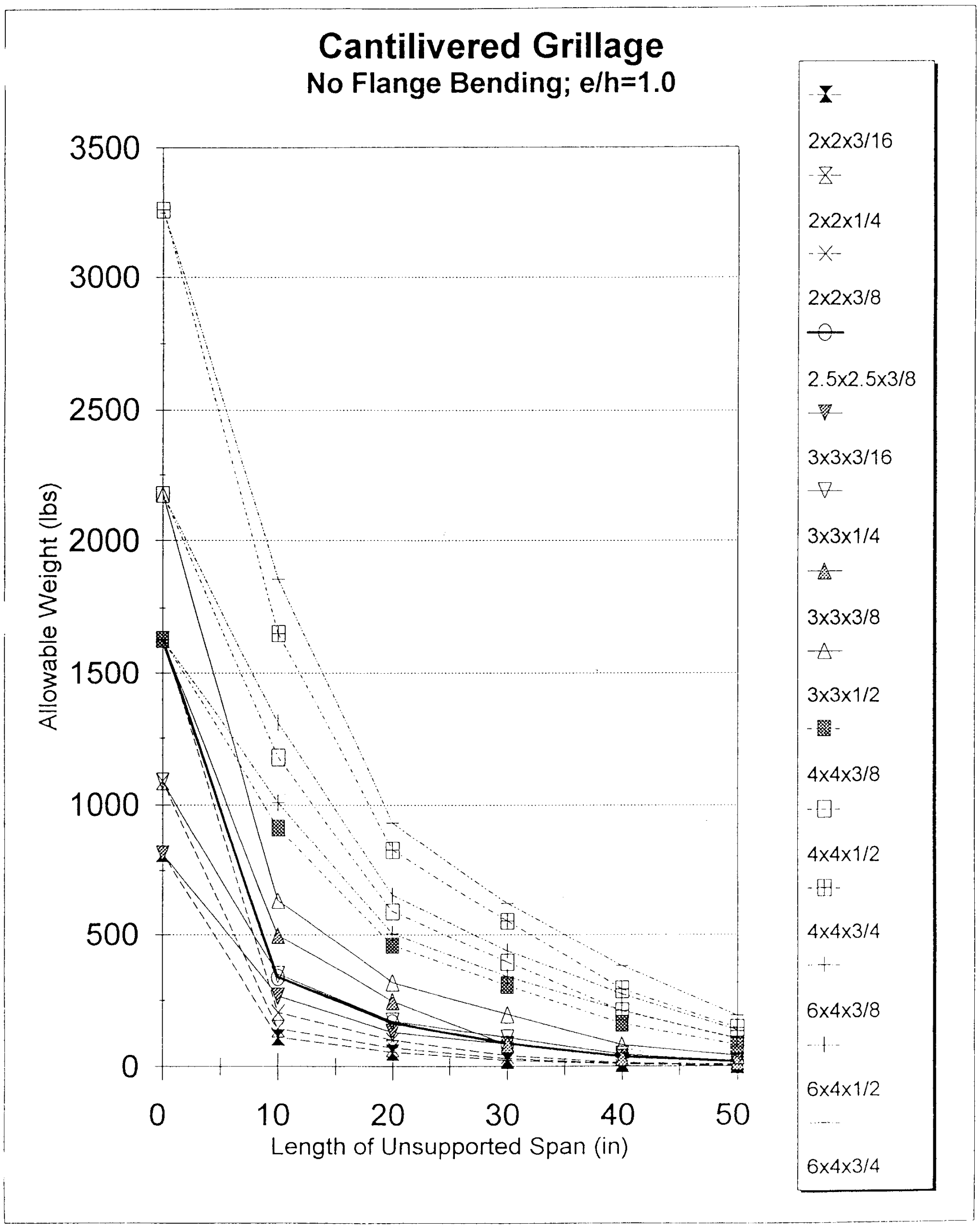


Figure 7-17 — Cantelevered Grillage, No Flange Bending; e/h = 1.0

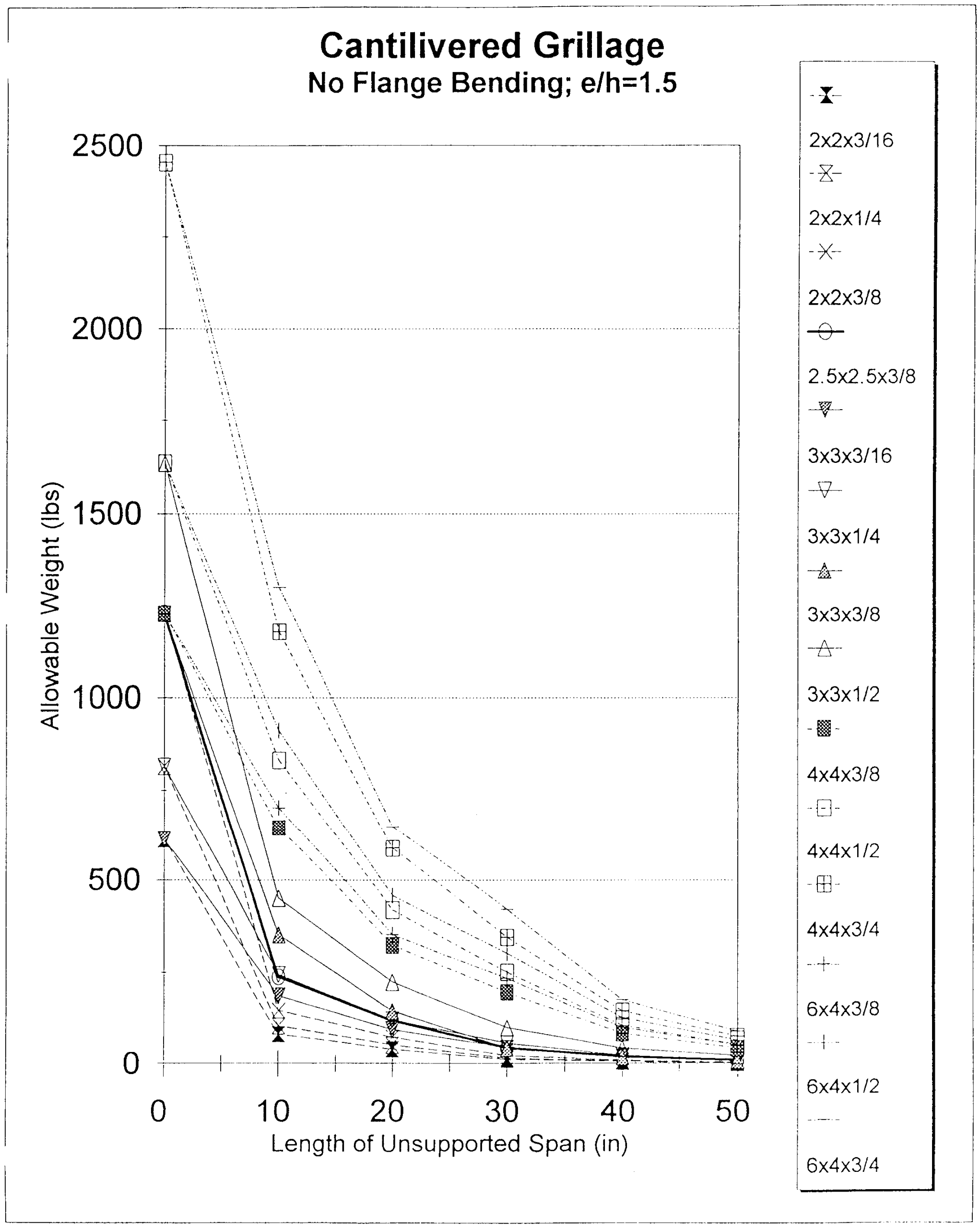


Figure 7-18 — Cantilevered Grillage, No Flange Bending; e/h = 1.5

ALLOWABLE GRILLAGE WEIGHTS — CANTILEVERED GRILLAGE — NO BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	40	126	74	52	176	104	73	287	169	120
30	61	24	12	78	31	16	108	43	22	192	88	44
40	26	10	5	33	13	7	46	18	9	94	37	19
50	13	5	3	17	7	3	23	9	5	48	19	10

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	187	99	68	337	179	122	780	414	282	1428	758	516
10	187	99	68	337	179	122	780	414	282	1075	635	451
20	187	99	68	299	174	122	425	250	140	540	319	226
30	154	79	39	199	107	53	216	86	43	360	198	99
40	89	35	18	117	46	23	92	37	18	211	84	42
50	46	18	9	60	24	12	47	19	9	108	43	22

	4×4×3/8			4×4×½			4×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	711	378	257	1290	685	466	3024	1606	1094
10	711	378	257	1290	685	466	3024	1606	1094
20	711	378	257	1007	591	418	1403	831	590
30	524	306	176	673	395	237	937	555	339
40	394	159	79	505	207	103	703	290	145
50	210	83	42	270	107	54	374	149	75

	6×4×3/8			6×4×½			6×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	654	347	236	1176	625	425	2713	1441	981
10	654	347	236	1176	625	425	2713	1441	981
20	654	347	236	1162	625	425	1647	933	651
30	600	338	173	776	438	254	1100	623	390
40	450	187	87	583	255	118	826	369	172
50	331	102	47	437	135	63	619	192	89

ALLOWABLE GRILLAGE WEIGHTS — CANTILEVERED GRILLAGE — BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

L	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	411	219	149	753	400	272	1632	956	651	1500	797	543
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	61	25	12	79	31	16	108	43	22	192	89	44
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

L	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	322	171	117	582	309	210	1350	717	488	2176	1316	896
10	322	171	117	582	309	210	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	144	540	319	226
30	154	83	41	199	110	55	217	87	43	360	200	100
40	91	36	18	118	47	23	92	37	18	211	84	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1200	638	434	2176	1157	788	3264	2720	1852
10	1200	638	434	2176	1157	788	3264	2720	1852
20	785	459	324	1007	591	418	1403	831	590
30	524	306	186	673	395	244	937	555	343
40	394	163	81	505	210	105	703	291	146
50	212	84	42	271	108	54	374	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1080	574	391	1944	1033	703	3264	2384	1623
10	1080	574	391	1944	1033	703	3264	2384	1623
20	898	507	353	1162	656	457	1647	933	651
30	600	338	200	776	438	276	1100	623	405
40	450	200	93	583	264	123	826	375	174
50	341	106	49	444	138	64	623	193	50

ALLOWABLE GRILLAGE WEIGHTS — GRILLAGE WITH SIMPLY SUPPORTED SPANS — NO FLANGE BENDING (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	62	25	12	79	31	16	108	43	22	192	89	45
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	458	268	188	595	348	246	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	147	540	319	226
30	154	87	44	199	113	56	218	87	44	360	201	100
40	92	37	18	119	48	24	92	37	18	212	85	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1560	914	647	2002	1178	835	2789	1656	1177
20	785	459	324	1007	591	418	1403	831	590
30	524	306	197	673	395	252	937	555	347
40	394	166	83	505	212	106	703	293	146
50	213	85	43	272	109	54	375	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1010	704	2176	1309	913	3264	1861	1300
20	898	507	353	1162	656	457	1647	933	651
30	600	338	235	776	538	303	1100	623	420
40	450	215	100	583	275	128	826	381	177
50	352	110	51	451	141	65	627	195	91

SOFT PLATE RESULTS

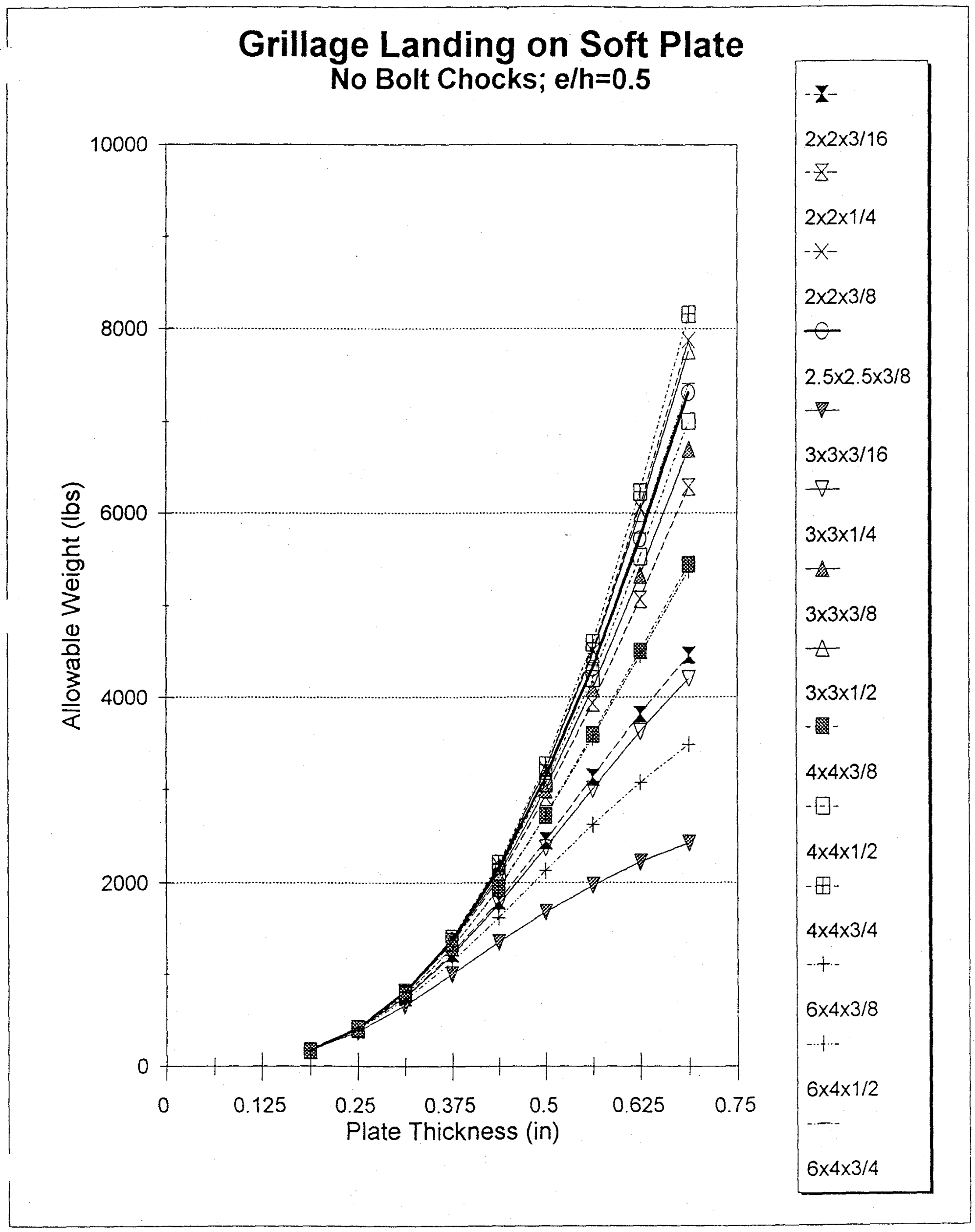


Figure 7-19 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 0.5

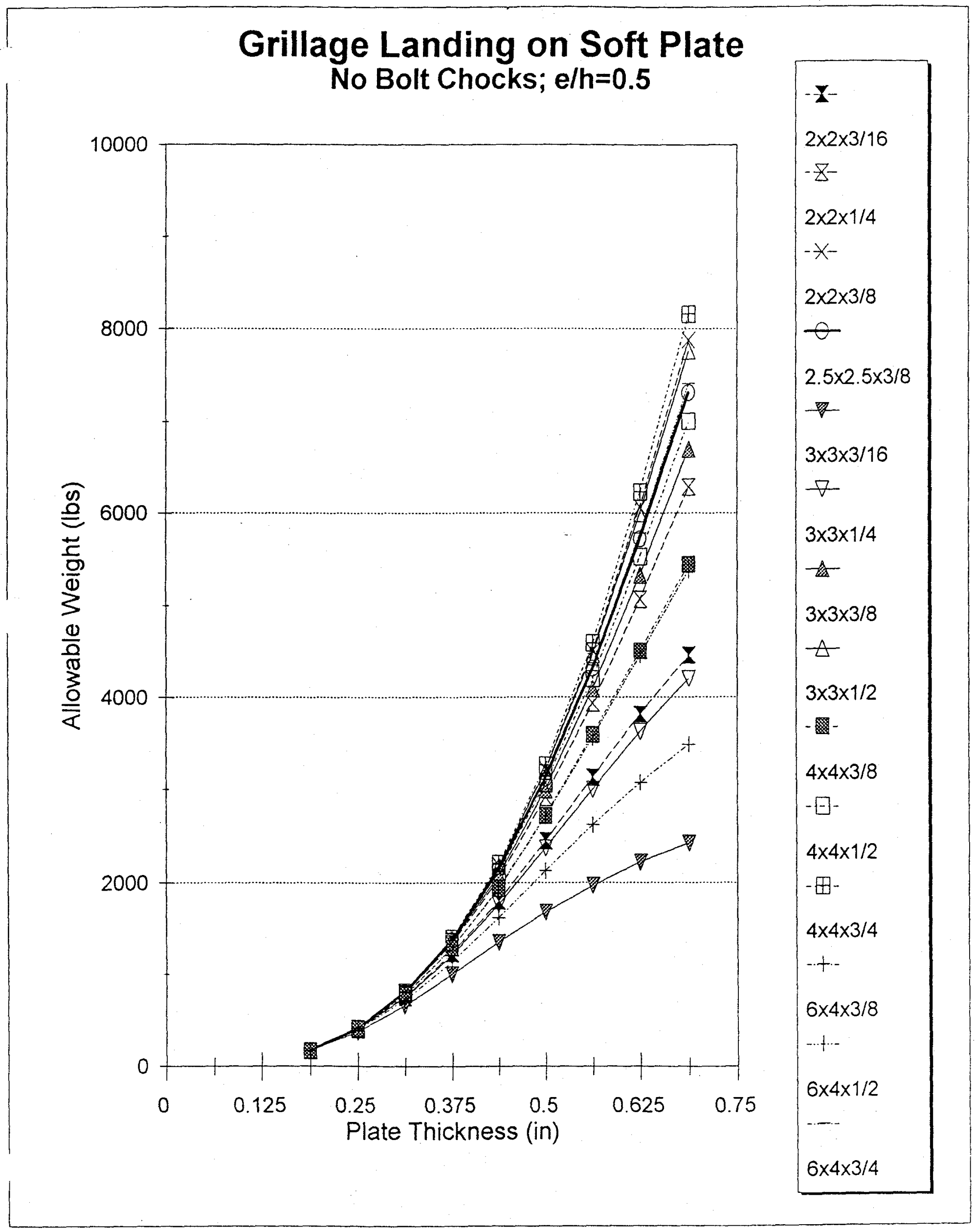


Figure 7-19 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 0.5

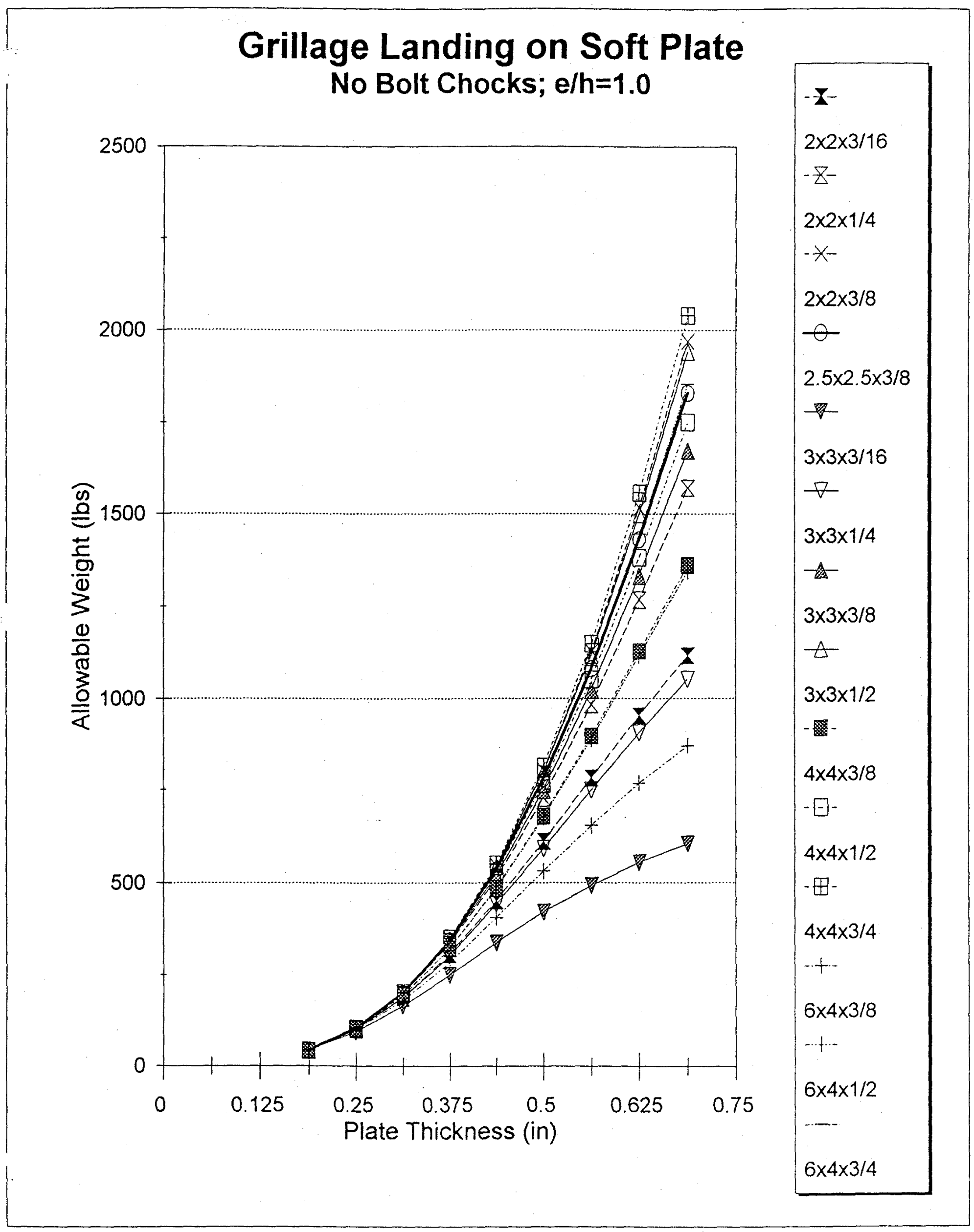


Figure 7-20 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 1.0

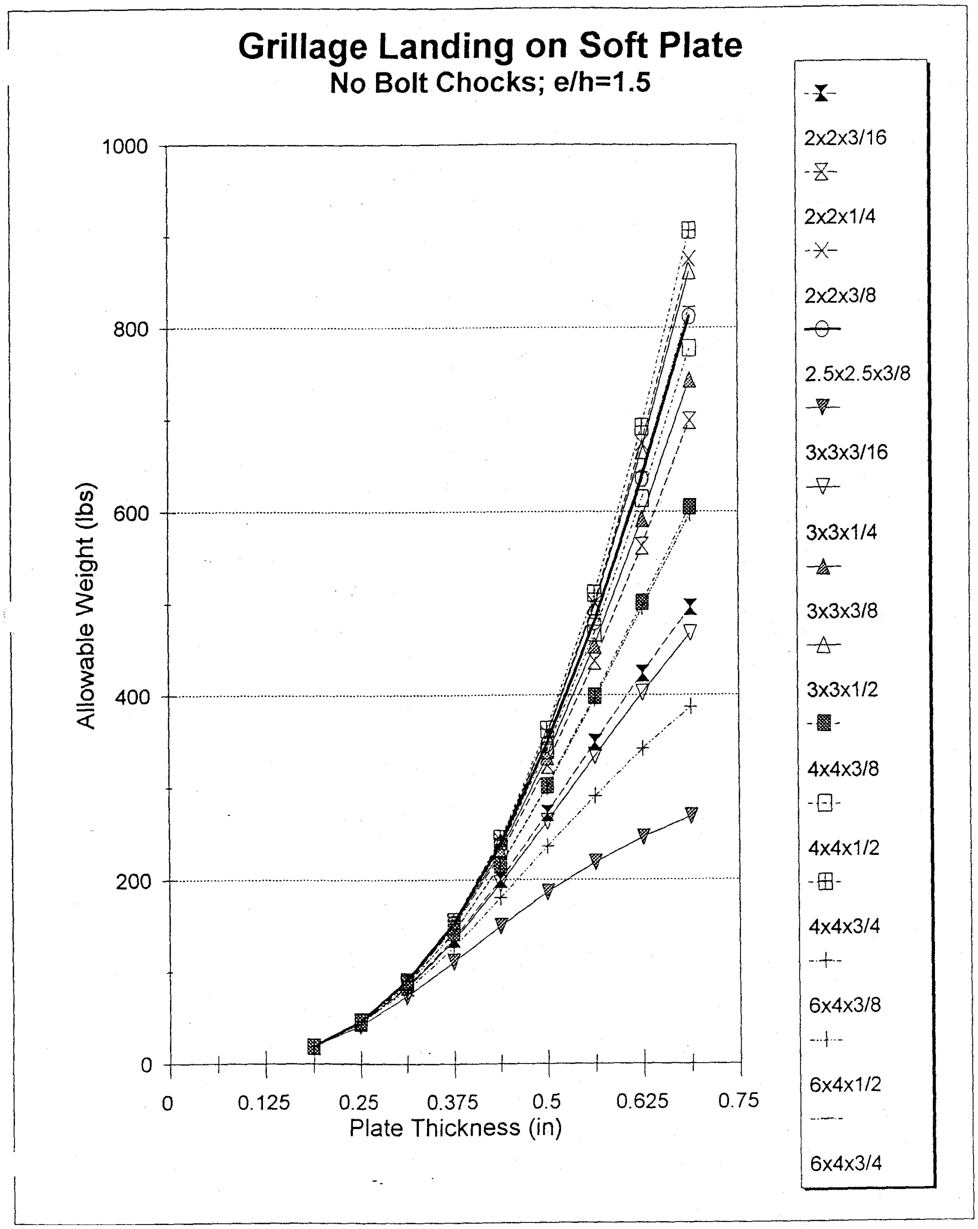


Figure 7-21 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 1.5

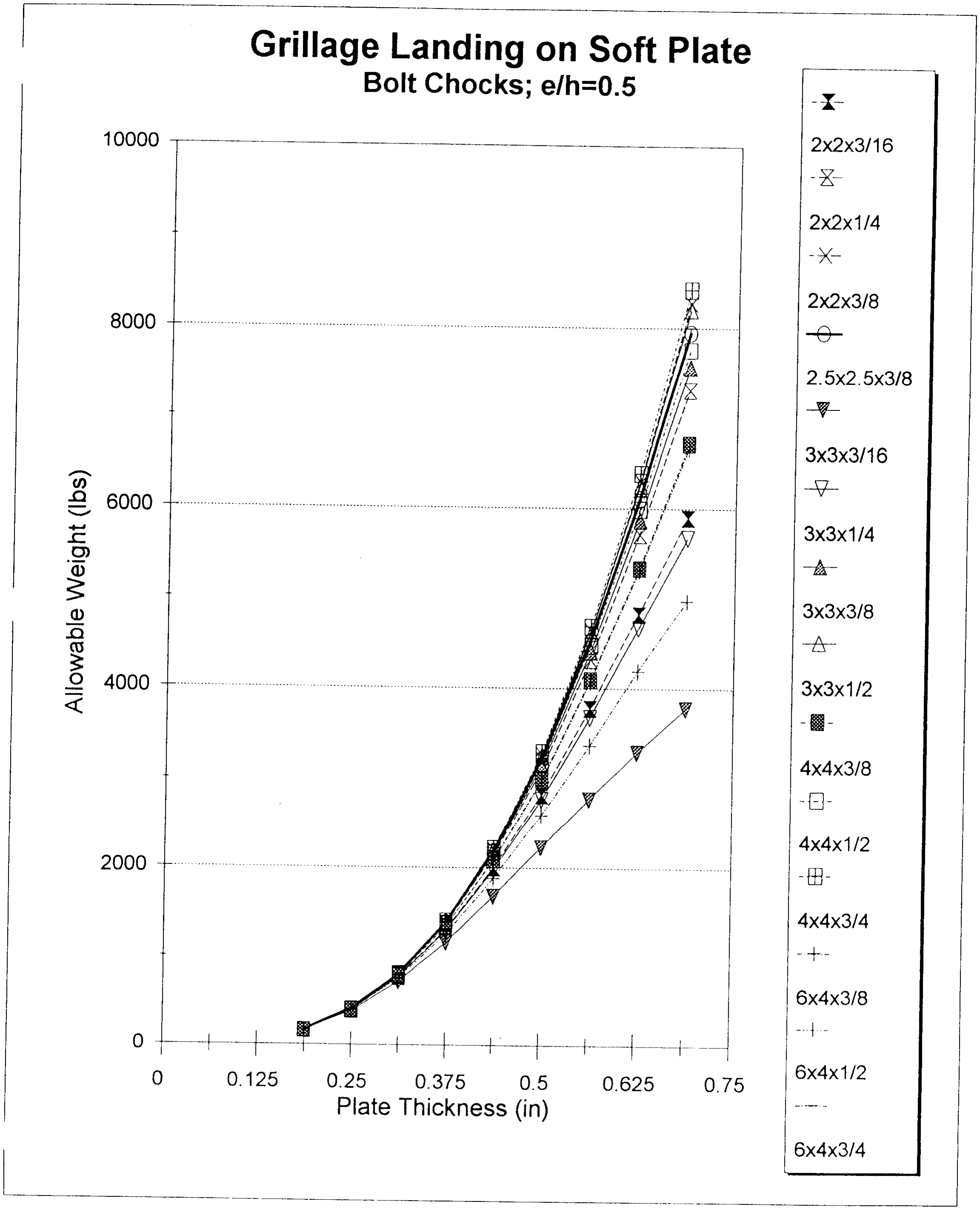


Figure 7-22 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 0.5

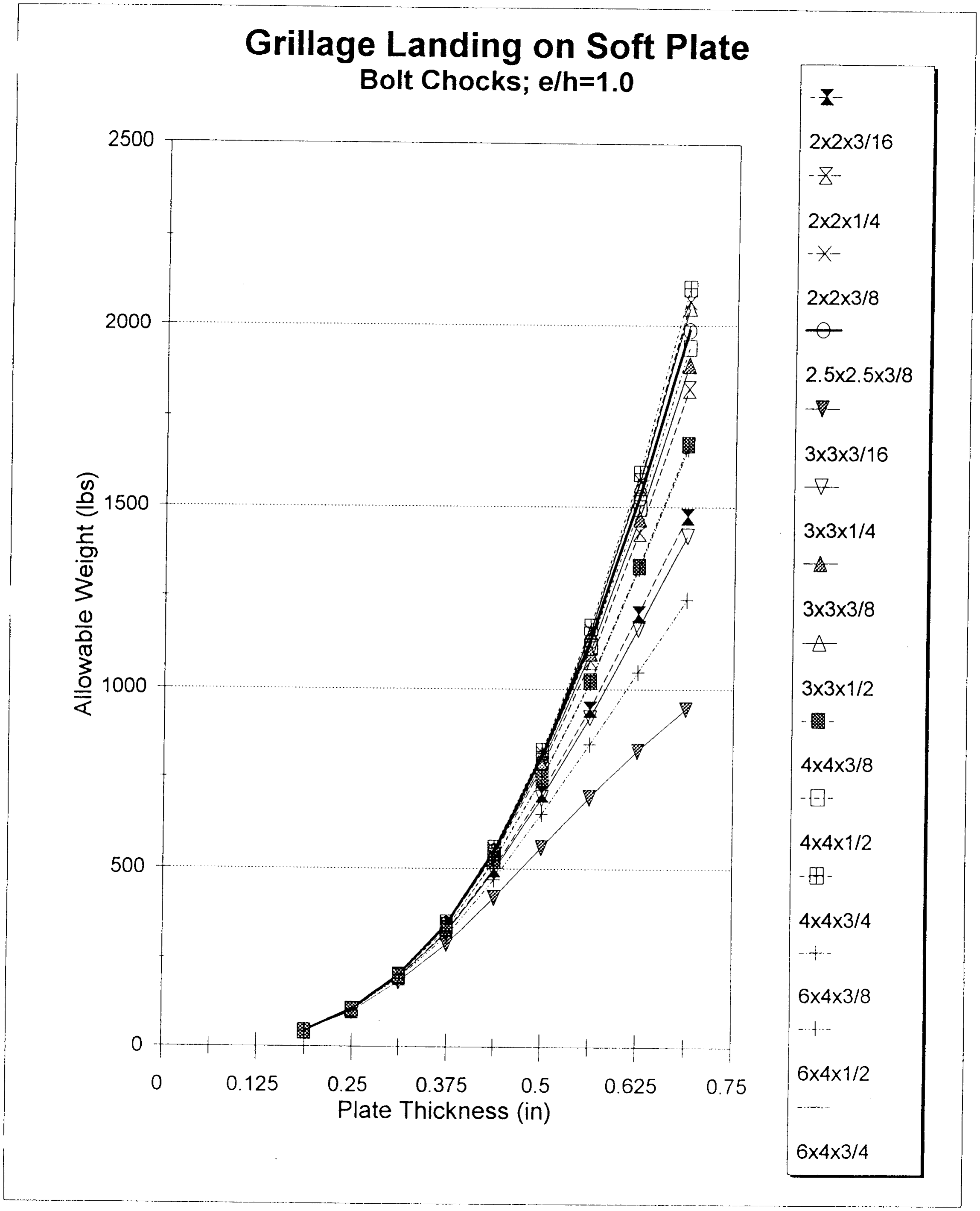


Figure 7-23 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 1.0

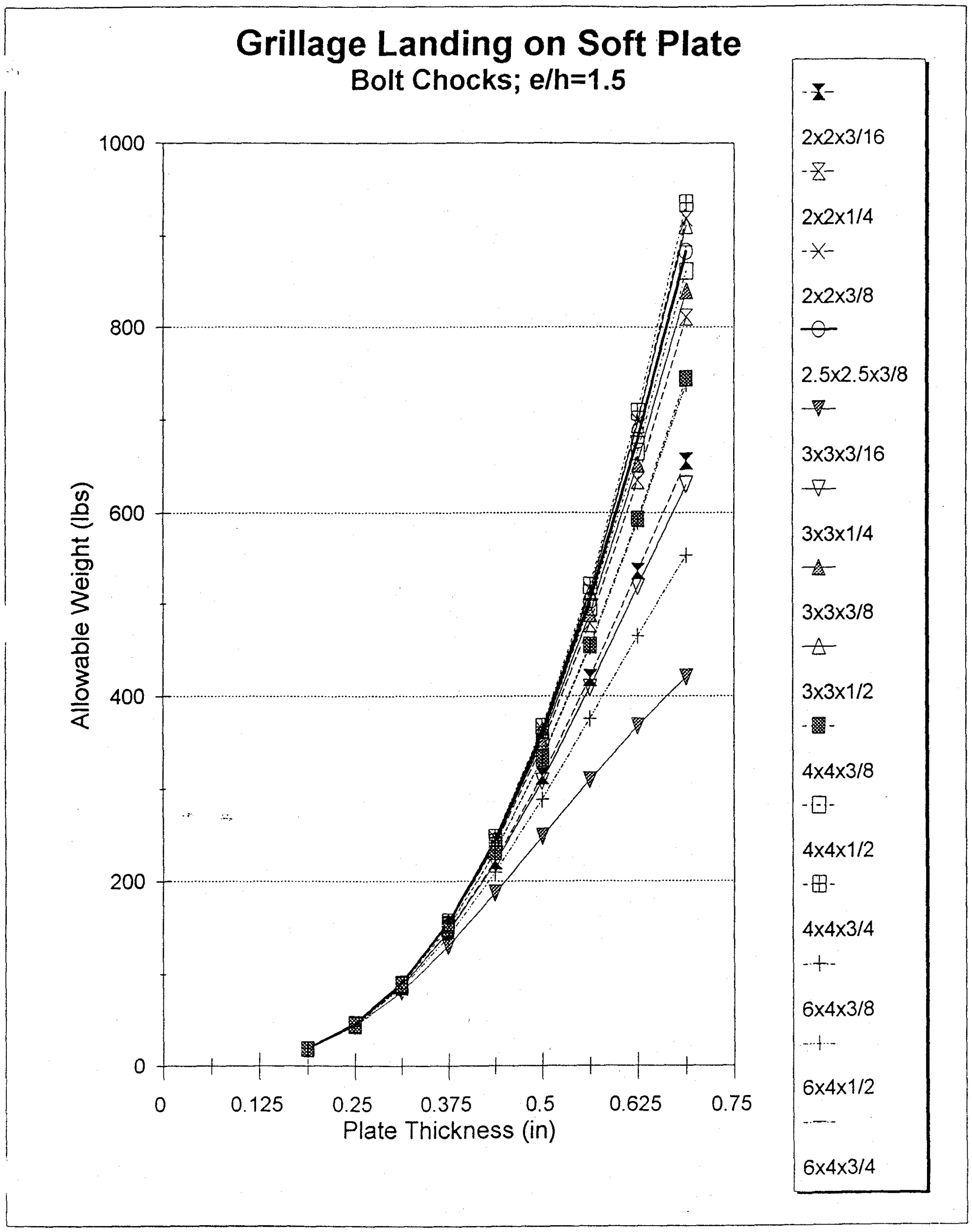


Figure 7-24 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 1.5

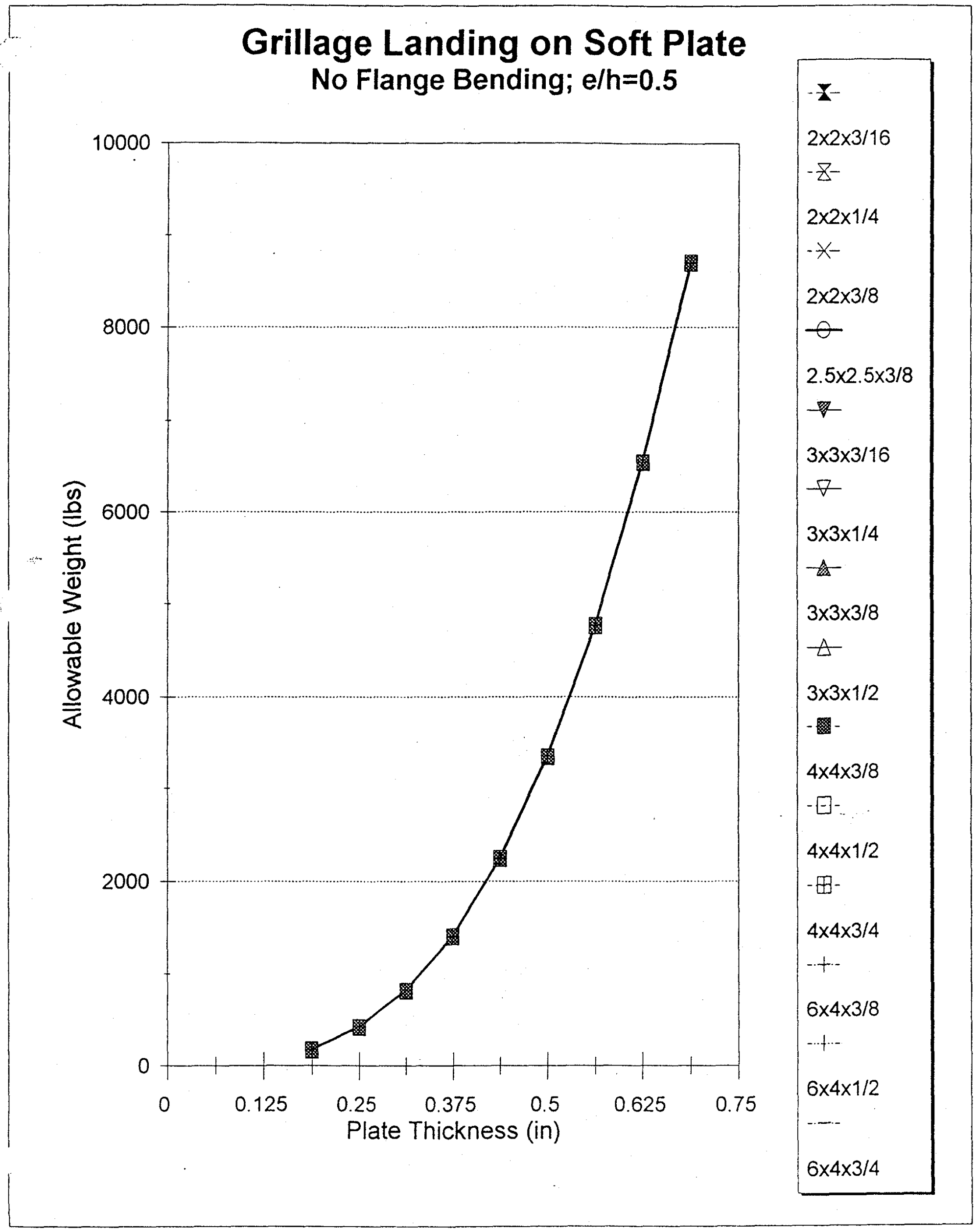


Figure 7-25 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 0.5

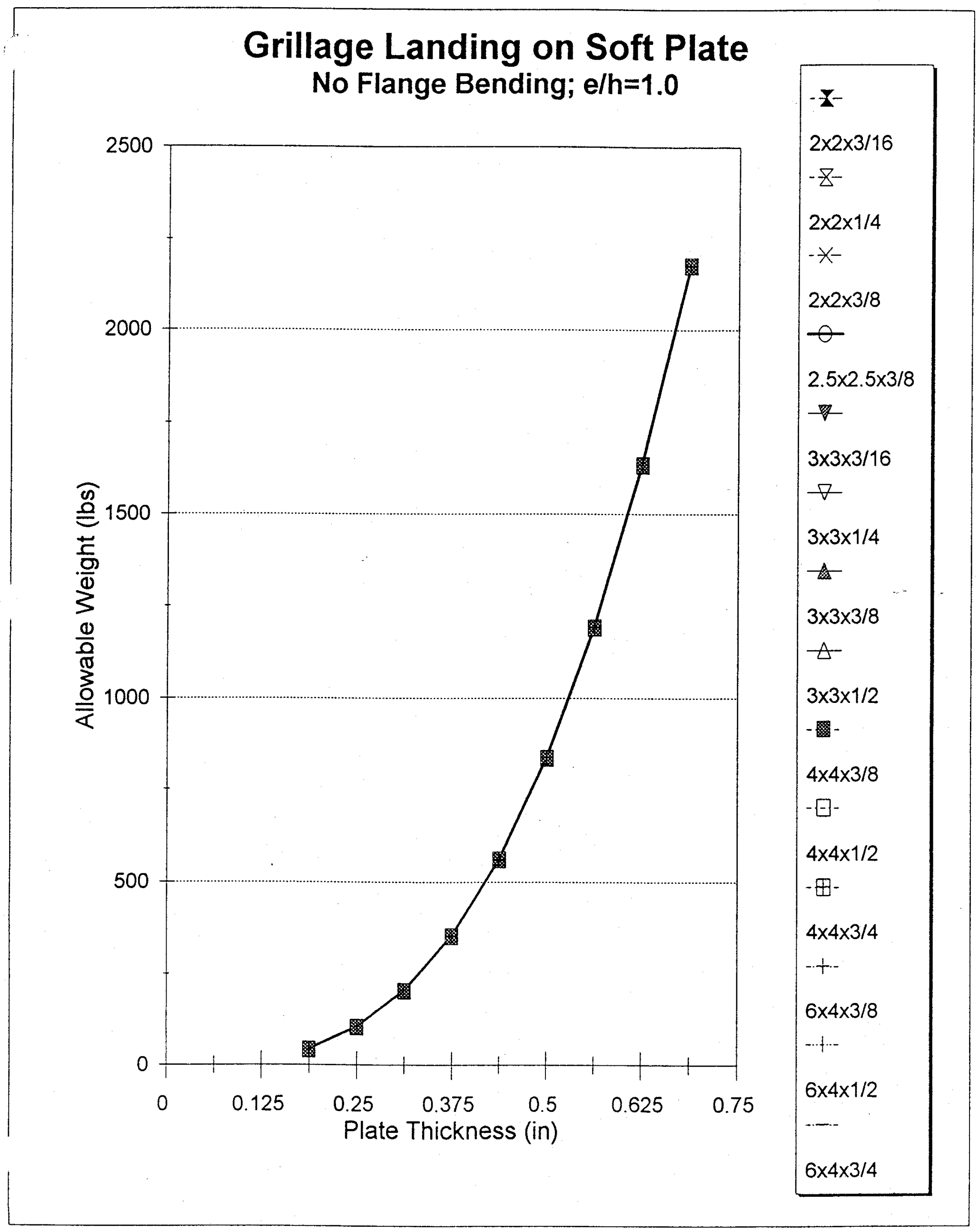


Figure 7-26 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 1.0

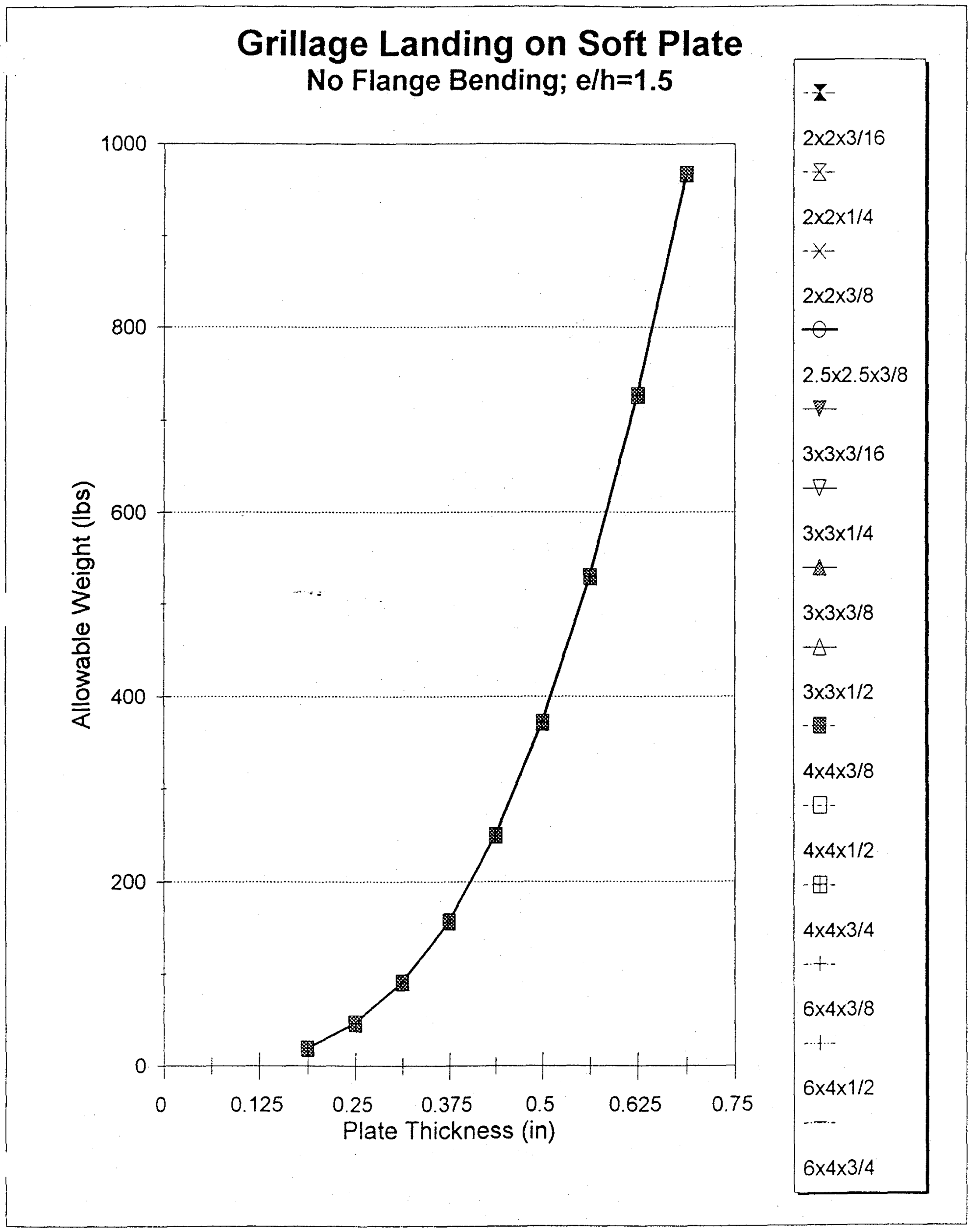


Figure 7-27 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 1.5

Table 7-1 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	173	43	19	175	44	19	176	44	20	176	44	20
0.2500	400	100	44	411	103	46	417	104	46	415	104	46
0.3125	751	188	83	789	197	88	810	202	90	804	201	89
0.3750	1225	306	136	1330	333	148	1390	347	154	1371	343	152
0.4375	1803	451	200	2042	510	227	2185	546	243	2140	535	238
0.5000	2453	613	273	2918	730	324	3221	805	358	3122	780	347
0.5625	3137	784	349	3940	985	438	4511	1128	501	4320	1080	480
0.6250	3817	954	424	5076	1269	564	6066	1517	674	5725	1431	636
0.6875	4465	1116	496	6289	1572	699	7884	1971	876	7317	1829	813

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	168	42	19	173	43	19	176	44	20	176	44	20
0.2500	372	93	41	398	100	44	413	103	46	416	104	46
0.3125	658	164	73	743	186	83	795	199	88	809	202	90
0.3750	994	249	110	1204	301	134	1348	337	150	1386	347	154
0.4375	1344	336	149	1760	440	196	2083	521	231	2177	544	242
0.5000	1676	419	186	2374	594	264	3003	751	334	3202	800	356
0.5625	1969	492	219	3009	752	334	4095	1024	455	4475	1119	497
0.6250	2217	554	246	3629	907	403	5336	1334	593	6000	1500	667
0.6875	2421	605	269	4210	1052	468	6694	1673	744	7772	1943	864

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20
0.2500	407	102	45	414	103	46	417	104	46
0.3125	774	194	86	800	200	89	813	203	90
0.3750	1288	322	143	1360	340	151	1398	350	155
0.4375	1944	486	216	2112	528	235	2206	552	245
0.5000	2723	681	303	3063	766	340	3266	817	363
0.5625	3592	898	399	4209	1052	468	4602	1150	511
0.6250	4513	1128	501	5531	1383	615	6230	1558	692
0.6875	5447	1362	605	7004	1751	778	8163	2041	907

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	171	43	19	174	44	19	176	44	20
0.2500	391	98	43	407	102	45	415	104	46
0.3125	717	179	80	773	193	86	805	201	89
0.3750	1137	284	126	1285	321	143	1374	344	153
0.4375	1619	405	180	1936	484	215	2148	537	239
0.5000	2125	531	236	2707	677	301	3139	785	349
0.5625	2620	655	291	3564	891	396	4354	1088	484
0.6250	3078	770	342	4469	1117	497	5785	1446	643
0.6875	3486	872	387	5384	1346	598	7415	1854	824

Table 7-2 — Allowable Grillage Weights — Grillage With Simply Supported Spans — No Flange Bending

(ALLOWABLE WEIGHT IN LBS.)

L	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	62	25	12	79	31	16	108	43	22	192	89	45
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

L	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	458	268	188	595	348	246	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	147	540	319	226
30	154	87	44	199	113	56	218	87	44	360	201	100
40	92	37	18	119	48	24	92	37	18	212	85	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1560	914	647	2002	1178	835	2789	1656	1177
20	785	459	324	1007	591	418	1403	831	590
30	524	306	197	673	395	252	937	555	347
40	394	166	83	505	212	106	703	293	146
50	213	85	43	272	109	54	375	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1010	704	2176	1309	913	3264	1861	1300
20	898	507	353	1162	656	457	1647	933	651
30	600	338	235	776	538	303	1100	623	420
40	450	215	100	583	275	128	826	381	177
50	352	110	51	451	141	65	627	195	91

Table 7-3 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	173	43	19	175	44	19	176	44	20	176	44	20
0.2500	400	100	44	411	103	46	417	104	46	415	104	46
0.3125	751	188	83	789	197	88	810	202	90	804	201	89
0.3750	1225	306	136	1330	333	148	1390	347	154	1371	343	152
0.4375	1803	451	200	2042	510	227	2185	546	243	2140	535	238
0.5000	2453	613	273	2918	730	324	3221	805	358	3122	780	347
0.5625	3137	784	349	3940	985	438	4511	1128	501	4320	1080	480
0.6250	3817	954	424	5076	1269	564	6066	1517	674	5725	1431	636
0.6875	4465	1116	496	6289	1572	699	7884	1971	876	7317	1829	813

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	168	42	19	173	43	19	176	44	20	176	44	20
0.2500	372	93	41	398	100	44	413	103	46	416	104	46
0.3125	658	164	73	743	186	83	795	199	88	809	202	90
0.3750	994	249	110	1204	301	134	1348	337	150	1386	347	154
0.4375	1344	336	149	1760	440	196	2083	521	231	2177	544	242
0.5000	1676	419	186	2374	594	264	3003	751	334	3202	800	356
0.5625	1969	492	219	3009	752	334	4095	1024	455	4475	1119	497
0.6250	2217	554	246	3629	907	403	5336	1334	593	6000	1500	667
0.6875	2421	605	269	4210	1052	468	6694	1673	744	7772	1943	864

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20
0.2500	407	102	45	414	103	46	417	104	46
0.3125	774	194	86	800	200	89	813	203	90
0.3750	1288	322	143	1360	340	151	1398	350	155
0.4375	1944	486	216	2112	528	235	2206	552	245
0.5000	2723	681	303	3063	766	340	3266	817	363
0.5625	3592	898	399	4209	1052	468	4602	1150	511
0.6250	4513	1128	501	5531	1383	615	6230	1558	692
0.6875	5447	1362	605	7004	1751	778	8163	2041	907

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	171	43	19	174	44	19	176	44	20
0.2500	391	98	43	407	102	45	415	104	46
0.3125	717	179	80	773	193	86	805	201	89
0.3750	1137	284	126	1285	321	143	1374	344	153
0.4375	1619	405	180	1936	484	215	2148	537	239
0.5000	2125	531	236	2707	677	301	3139	785	349
0.5625	2620	655	291	3564	891	396	4354	1088	484
0.6250	3078	770	342	4469	1117	497	5785	1446	643
0.6875	3486	872	387	5384	1346	598	7415	1854	824

Table 7-4 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20	176	44	20
0.2500	409	102	45	415	104	46	418	104	46	417	104	46
0.3125	783	196	87	803	201	89	814	203	90	811	203	90
0.3750	1312	328	146	1371	343	152	1401	350	156	1392	348	155
0.4375	2000	500	222	2138	535	238	2215	554	246	2191	548	243
0.5000	2832	708	315	3119	780	347	3284	821	365	3232	808	359
0.5625	3785	946	421	4315	1079	479	4637	1159	515	4534	1133	504
0.6250	4822	1205	536	5717	1429	635	6296	1574	700	6107	1527	679
0.6875	5904	1476	656	7304	1826	812	8276	2069	920	7953	1988	884

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	172	43	19	175	44	19	176	44	20	176	44	20
0.2500	394	99	44	408	102	45	416	104	46	418	104	46
0.3125	729	182	81	779	195	87	807	202	90	813	203	90
0.3750	1167	292	130	1301	325	145	1380	345	153	1400	350	156
0.4375	1682	420	187	1973	493	219	2161	540	240	2210	553	246
0.5000	2234	559	248	2779	695	309	3167	792	352	3274	819	364
0.5625	2787	697	310	3690	923	410	4407	1102	490	4618	1154	513
0.6250	3312	828	368	4669	1167	519	5879	1470	653	6260	1565	696
0.6875	3789	947	421	5676	1419	631	7570	1892	841	8214	2054	913

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	176	44	20	176	44	20	177	44	20
0.2500	413	103	46	416	104	46	418	105	46
0.3125	796	199	88	809	202	90	815	204	91
0.3750	1348	337	150	1386	347	154	1406	351	156
0.4375	2084	521	232	2176	544	242	2225	556	247
0.5000	3004	751	334	3200	800	356	3308	827	368
0.5625	4098	1025	455	4472	1118	497	4684	1171	520
0.6250	5342	1335	594	5995	1499	666	6383	1596	709
0.6875	6703	1676	745	7764	1941	863	8427	2107	936

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	174	44	19	176	44	20	176	44	20
0.2500	404	101	45	413	103	46	417	104	46
0.3125	764	191	85	795	199	88	811	203	90
0.3750	1260	315	140	1346	336	150	1394	348	155
0.4375	1881	470	209	2079	520	231	2195	549	244
0.5000	2601	650	289	2995	749	333	3241	810	360
0.5625	3382	846	376	4080	1020	453	4553	1138	506
0.6250	4187	1047	465	5311	1328	590	6141	1535	682
0.6875	4979	1245	553	6654	1664	739	8010	2003	890

Table 7-5 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Flange Bending

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968

APPLICATION OF RESULTS

It is intended that a designer will be able to pick a proper grillage configuration and angle based on these curves, and, based on the soft plate curves, determine whether or not back up structure is necessary. The designer will begin this process with some preliminary information: the location of the equipment, the equipment's weight, the equipment's center of gravity, and the bolting pattern. With this information, he can determine from what structure the foundation can be hung (plating or stiffeners), he can calculate the e/h of the equipment (equipment center of gravity over the minimum orthogonal bolt spacing), and he can determine the preliminary flange condition (partially fixed at the heel, fully fixed at the heel, or no flange bending possible). Based on this information, the designer can determine the required angle size for his grillage. If the result of this initial check is unsatisfactory, the designer can then use these same design curves to reiterate the grillage to allow the use of a smaller angle size. The proposed process for designing a grillage is thus as follows.

GRILLAGES LANDING ON SHIP STRUCTURE

The first step in this process is to determine the location of the grillage spans and where the grillage ties into ship structure. If possible, especially with heavy equipments, it is desirable to land the grillage or its chocks on stiffeners as this avoids any potential need for back-up structure. Different equipment locations may result in a wide variety of configurations. A grillage may be cantilevered off of stiffeners, it may be simply supported between chocks, or it might contain multiple spans where one bolt lands on a grillage supported between stiffeners and another lands on a span cantilevered off of a stiffener. Whatever the case, in determining the angle size, it is important to use the worst configuration that exists for that particular grillage. Thus, it may be necessary to check both a simply supported span and a cantilevered span and use the most conservative angle size.

Once the preliminary grillage configuration is laid out, it is possible to determine the preliminary angle size using the e/h, flange condition, and length of the grillage span. If flange bending is possible, the condition at the heel of the angle (fully or partially fixed) can be determined from *Figure 7-1*. The length of span used should be the longest span on the grillage. The allowable curves can then be used to find the minimum angle size that is capable of carrying the equipment weight. It should be noted that these curves were generated based on a single span grillage and the allowable weights are therefore an allowable per span. Thus, with multiple span grillages where at least one bolt lands on each span, the weight of the equipment may be divided by the number of spans supporting the equipment when determining the required angle size. In doing this, the worst span should be used, based on length and configuration. A span is defined as two or more parallel angles bounded by common support points. If the resultant angle size is not desirable, the designer can modify the configuration by adding more spans, shortening the span length, or changing the flange bending condition in order to allow a smaller angle size to be used.

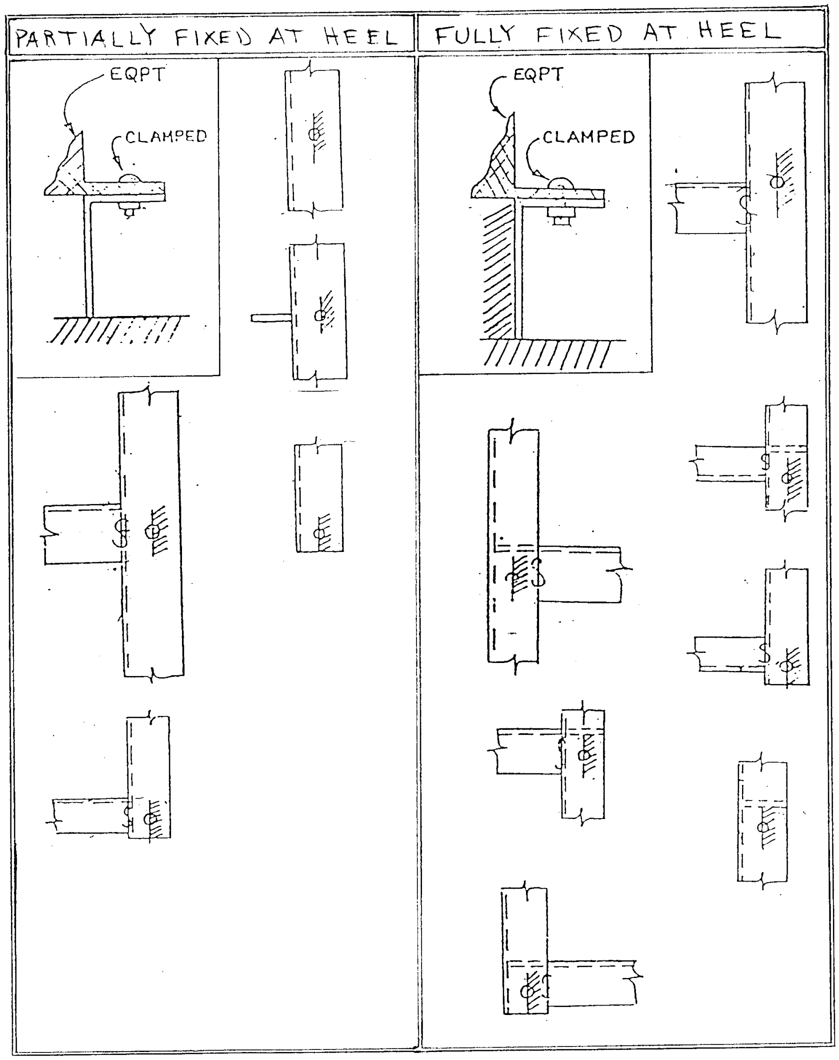


Figure 7-1 — Conditions of Flange Heel Fixity

GRILLAGES LANDING ON SOFT PLATE

A similar procedure is used in determining angle size for grillages landing on soft plate. In this instance it is necessary to check two sets of curves: one to determine the required angle size and one to determine whether back-up structure is required. First, the angle size is determined from the curves for simply supported spans using a length of span of zero. The simply supported curves are used since no grillage landing on soft plate should be cantilevered, and a length of zero is used because the purpose of landing on soft plate is to avoid unnecessary grillage structure so the bolts should land at the chock support. With the required angle size determined, the soft plate acceptability can then be checked.

The purpose of the soft plate curves is to determine whether or not it is acceptable to land a particular grillage on soft plate. For the equipment e/h, angle size used, flange bending condition at the heel and thickness of the soft plate, an allowable weight is determined. If this weight is greater than the equipment weight, then it is permissible to land the equipment on soft plate. If the allowable weight is less than the equipment weight, then back-up structure must be added or the grillage must be redesigned to tie-in directly with ship structure. As was the case for determining angle size, where multiple grillage spans exist, the equipment weight may be divided by the number of spans when checking the soft plate curves.

CONCLUSIONS AND RECOMMENDATIONS

The allowables determined from this analysis are extremely conservative. They use worst case bending, frequency, and flange configurations which produce relatively low allowables for the different angle sizes. If more variables were included as input to these curves, such as bolt spacing, actual bolt distance to the web and number of bolts, it would be possible to increase the weight allowed by a given angle size. The results of this would be longer spans, more grillages which could be cantilevered, and in general, less required welding and fitting for many grillages. However, this improvement would have to be weighed against the increased complexity for designers who would have to contend with determining these added variables and then sort through a larger set of curves to determine angle sizes. One possible solution to this dilemma is to replace the allowable curves with a set of design data sheets.

ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

BACKGROUND / APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16". However, it may be possible to broaden the use of robots through the use of standard construction details for both structure and outfit and especially equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards..

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant "MAP" would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling, or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness and other characteristics) in order to complete the weld or other construction sequence.

The robot with "3-D" vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach pendant will orient the robot to its work and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvement in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for "actual" distortions, skewness, and irregularities will usher in advanced applications for robots.

TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, limitations in following prescribed tool paths. Characterize state of the art in 3-D vision systems and teachable robots

2. Define parameters for the constraints on robots, standards, 3-D vision systems, and teach pendant systems.

3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.

4. Select Candidate structural/outfitting details, portable robotic systems, 3-D vision systems, and teachable control systems to develop candidate applications for portable robotic systems.

5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

PIPE RUN NATURAL FREQUENCY ANALYSIS TABLES

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	21.62	AXIAL	29.7	2.1	29.2	20.4		
12 INCH STANDOFF		SHEAR	23.3	1.1	1.5	11.3		
4 INCH PIPE	17.70	AXIAL	244.0	116.0	197.0	144.0		
12 INCH STANDOFF		SHEAR	90.2	12.7	3.1	47.7		
12 INCH PIPE	3.43	AXIAL	2135.0	925.0	1590.0	1239.0		
12 INCH STANDOFF		SHEAR	109.6	16.5	42.2	59.4		

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	22.45	AXIAL	50.7	45.8	50.6	45.8		
12 INCH STANDOFF		SHEAR	12.1	0.0	0.0	5.8		
4 INCH PIPE	11.99	AXIAL	255.7	147.0	228.1	163.4		
12 INCH STANDOFF		SHEAR	93.3	8.5	18.8	47.5		
12 INCH PIPE	4.49	AXIAL	2143.0	957.9	1628.0	1256.0		
12 INCH STANDOFF		SHEAR	204.0	29.6	75.1	110.0		

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	22.47	AXIAL	88.9	91.2	88.8	91.3		
12 INCH STANDOFF		SHEAR	8.7	0.0	0.0	4.2		
4 INCH PIPE	11.19	AXIAL	293.3	192.8	266.9	208.5		
12 INCH STANDOFF		SHEAR	65.3	5.3	11.8	33.3		
12 INCH PIPE	4.54	AXIAL	2181.0	1004.0	1667.0	1301.0		
12 INCH STANDOFF		SHEAR	143.5	2.0	51.0	77.3		

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.09	AXIAL	28.9	19.4	28.7	19.5	29.2	20.4
12 INCH STANDOFF		SHEAR	0.0	0.0	17.7	0.0	3.0	10.6
4 INCH PIPE	9.11	AXIAL	222.5	131.9	232.8	128.7	194.9	148.4
12 INCH STANDOFF		SHEAR	8.7	0.0	7.4	6.8	34.2	46.0
12 INCH PIPE	1.52	AXIAL	1924.0	939.0	2178.0	957.0	1586.0	1253.0
12 INCH STANDOFF		SHEAR	35.1	7.5	115.4	10.9	49.8	54.7

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	16.9	AXIAL	49.9	36.2	49.9	46.1	50.6	45.9
12 INCH STANDOFF		SHEAR	0.0	0.0	9.2	0.0	0.0	5.4
4 INCH PIPE	12.45	AXIAL	241.2	142.5	242.9	153.7	227.2	165.5
12 INCH STANDOFF		SHEAR	61.3	3.7	71.0	2.5	24.7	45.1
12 INCH PIPE	2.24	AXIAL	1934.0	1012.0	2147.0	995.0	1620.0	1263.0
12 INCH STANDOFF		SHEAR	52.0	11.8	204.8	19.0	89.5	101.0

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	17.13	AXIAL	88.1	64.7	88.0	91.4	88.8	91.3
12 INCH STANDOFF		SHEAR	0.0	0.0	6.6	0.0	0.0	3.9
4 INCH PIPE	12.17	AXIAL	279.2	172.7	279.6	199.3	266.0	210.2
12 INCH STANDOFF		SHEAR	7.1	3.6	49.1	1.1	16.4	31.2
12 INCH PIPE	2.31	AXIAL	1968.0	1057.0	2170.0	1050.0	1657.0	1310.0
12 INCH STANDOFF		SHEAR	56.2	11.8	146.5	9.3	66.5	67.7

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	12.97	AXIAL	28.9	18.8	28.1	45.3	37.5	20.4
12 INCH STANDOFF		SHEAR	0.0	1.2	28.8	30.2	45.7	7.7
4 INCH PIPE	9.11	AXIAL	221.6	135.8	209.1	211.5	239.8	141.0
12 INCH STANDOFF		SHEAR	9.6	4.9	108.6	52.7	108.0	52.7
12 INCH PIPE	1.52	AXIAL	1923.0	956.0	2022.0	1457.0	1907.0	1152.0
12 INCH STANDOFF		SHEAR	41.2	9.0	159.0	53.2	121.0	67.2

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	13.43	AXIAL	49.9	36.1	49.7	70.5	58.5	45.8
12 INCH STANDOFF		SHEAR	0.0	0.0	14.2	15.4	23.0	3.6
4 INCH PIPE	12.45	AXIAL	241.5	141.6	226.6	232.9	265.1	160.1
12 INCH STANDOFF		SHEAR	5.8	4.5	97.5	54.7	108.5	48.6
12 INCH PIPE	2.24	AXIAL	1931.0	1035.0	1985.0	1498.0	1936.0	1194.0
12 INCH STANDOFF		SHEAR	59.8	14.2	281.3	99.1	223.3	122.8

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	13.44	AXIAL	88.1	64.6	87.9	115.8	96.7	91.3
12 INCH STANDOFF		SHEAR	0.0	0.0	9.6	10.6	15.7	2.4
4 INCH PIPE	12.16	AXIAL	278.9	171.3	263.6	278.4	303.5	204.8
12 INCH STANDOFF		SHEAR	6.7	4.2	66.4	37.1	73.9	33.5
12 INCH PIPE	2.31	AXIAL	1965.0	1083.0	2006.0	1553.0	1972.0	1241.0
12 INCH STANDOFF		SHEAR	64.7	14.3	199.5	64.3	159.9	82.4

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	24.80	AXIAL	0.0	17.4	0.0	16.0		
12 INCH STANDOFF		SHEAR	12.3	2.1	1.1	0.9		
4 INCH PIPE	20.40	AXIAL	0.0	154.4	0.0	139.2		
12 INCH STANDOFF		SHEAR	82.8	17.4	30.1	13.4		
12 INCH PIPE	3.95	AXIAL	0.0	1602.0	0.0	1115.0		
12 INCH STANDOFF		SHEAR	498.6	66.4	21.9	66.0		

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	25.82	AXIAL	0.0	33.5	0.0	29.0		
12 INCH STANDOFF		SHEAR	17.8	4.3	16.1	3.7		
4 INCH PIPE	13.79	AXIAL	0.0	203.5	0.0	148.5		
12 INCH STANDOFF		SHEAR	38.9	11.7	10.5	8.9		
12 INCH PIPE	5.16	AXIAL	0.0	1894.0	0.0	987.0		
12 INCH STANDOFF		SHEAR	279.1	33.0	50.5	32.6		

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	25.84	AXIAL	0.0	55.9	0.0	50.0		
12 INCH STANDOFF		SHEAR	31.4	11.8	28.5	12.8		
4 INCH PIPE	12.87	AXIAL	0.0	236.1	0.0	168.0		
12 INCH STANDOFF		SHEAR	66.8	3.4	19.5	8.1		
12 INCH PIPE	5.22	AXIAL	0.0	1944.0	0.0	996.1		
12 INCH STANDOFF		SHEAR	273.4	15.9	39.7	14.7		

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	17.35	AXIAL	0.8	1.8	0.7	17.0	0.0	16.0
12 INCH STANDOFF		SHEAR	9.9	0.6	7.3	1.3	10.6	0.8
4 INCH PIPE	10.48	AXIAL	2.3	62.3	33.5	146.5	2.9	122.6
12 INCH STANDOFF		SHEAR	38.5	82.9	24.3	6.1	8.9	11.8
12 INCH PIPE	1.75	AXIAL	20.0	591.0	248.6	1410.0	29.1	1022.0
12 INCH STANDOFF		SHEAR	490.2	789.2	25.4	19.9	5.8	27.9

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	19.44	AXIAL	1.1	9.6	0.9	30.8	0.0	29.0
12 INCH STANDOFF		SHEAR	5.5	20.9	0.2	2.3	1.2	1.4
4 INCH PIPE	14.32	AXIAL	6.1	91.9	37.5	174.6	1.5	143.2
12 INCH STANDOFF		SHEAR	61.5	110.7	33.8	29.6	14.6	29.7
12 INCH PIPE	2.58	AXIAL	43.4	699.5	443.7	1580.0	48.4	1071.0
12 INCH STANDOFF		SHEAR	582.6	881.0	11.7	40.6	1.2	59.9

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	19.70	AXIAL	88.1	64.7	88.0	91.4	88.8	91.3
12 INCH STANDOFF		SHEAR	0.6	0.0	0.6	14.8	0.0	14.9
4 INCH PIPE	13.99	AXIAL	279.2	172.9	279.6	199.3	266.0	210.2
12 INCH STANDOFF		SHEAR	7.1	3.6	49.1	1.1	16.4	31.2
12 INCH PIPE	2.66	AXIAL	1968.0	1057.0	2170.0	1050.0	1657.0	1310.0
12 INCH STANDOFF		SHEAR	56.2	11.8	146.5	9.3	66.5	67.7

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	14.92	AXIAL	0.9	1.9	0.2	41.8	8.2	15.6
12 INCH STANDOFF		SHEAR	9.9	0.6	7.1	1.3	1.1	0.9
4 INCH PIPE	10.48	AXIAL	2.8	57.6	20.6	212.4	38.9	122.4
12 INCH STANDOFF		SHEAR	37.8	82.2	44.1	50.2	21.6	11.0
12 INCH PIPE	1.75	AXIAL	19.7	553.4	179.9	1765.0	262.9	102.0
12 INCH STANDOFF		SHEAR	486.4	771.5	50.9	41.8	23.6	26.2

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.45	AXIAL	1.1	9.7	0.8	55.3	7.9	28.9
12 INCH STANDOFF		SHEAR	5.5	20.9	4.5	16.0	12.6	2.1
4 INCH PIPE	14.32	AXIAL	6.1	90.4	28.2	243.5	33.1	141.6
12 INCH STANDOFF		SHEAR	61.7	109.9	50.3	68.3	19.6	26.8
12 INCH PIPE	2.58	AXIAL	42.5	657.4	368.1	1837.0	278.4	1070.0
12 INCH STANDOFF		SHEAR	578.2	868.0	150.9	86.6	51.4	60.2

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.46	AXIAL	88.1	64.6	87.9	115.8	96.7	91.3
12 INCH STANDOFF		SHEAR	0.5	0.4	9.6	10.6	15.7	2.4
4 INCH PIPE	12.16	AXIAL	278.9	171.3	263.6	278.4	303.5	204.8
12 INCH STANDOFF		SHEAR	6.7	4.2	66.4	37.1	73.9	33.5
12 INCH PIPE	2.31	AXIAL	1965.0	1083.0	2006.0	1553.0	1972.0	1241.0
12 INCH STANDOFF		SHEAR	64.7	14.3	199.5	64.3	159.9	82.4

NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATION

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NO. 8 — PRODUCT MODELING CRITERIA AND DEMONSTRATION

PRINCIPAL INVESTIGATOR:
DOMINIC BURNS
SENIOR ENGINEER
NATIONAL STEEL AND SHIPBUILDING COMPANY

ADDITIONAL INVESTIGATOR:
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TABLE OF CONTENTS

8 PRODUCT MODELING CRITERIA/ATTRIBUTES & DEMONSTRATE

This section describes and outlines the processes related to the design of Equipment Installations. The various Engineering and design tools developed in the previous sections and the methods associated with them will be described here. This section will attempt to relay a practical example of the basic application of the tools. The result of this described exercise should result in an Equipment Installation that has been through a cognizant process of calculation, validation, product modeling, and final design. The consequent design will be for an installation that is more producible in terms of materials, methods, and manhours.

STANDARDS SELECTION

Based on the ship functionality and scantling plan, an applicable standard mounting method and foundation is chosen and validated. The primary driver for the standards determination will be to support the Build Strategy for the shipyard for the particular contract.

For example, a typical crude oil tanker will most probably have a need for a pipe rack on the weather deck. The Build Strategy for this tanker might address producibility issues as they relate to certain facilities and timelines. Therefore, the different options for above deck pipe racks should be qualified.

ENGINEERING ANALYSIS SPREADSHEET

In order to validate a chosen standard and to develop an acceptable scantling plan for the Equipment Installation, the Engineering Analysis Spreadsheet is used as a tool to calculate dimensional requirements for the standard and scantling in process.

A spreadsheet has been developed to aid designers in determining the required scantling for the most common scenarios. These are single run hangers, single run hangers with bracing, racking systems with legs and structural attachments, and goal post racking systems with variable number of legs. These scenarios can be calculated using different configurations. These are forward and aft runs supported horizontally, athwartship runs supported horizontally, vertical runs mounted to longditudinal and athwartship bulkheads.

This spreadsheet determines the minimum section modulus and defaults to the required scantling. The scantling which can be chosen should reflect the raw material stock carried by the particular shipyard.

In the past there was no simple and consistent manner to determine scantling sizes. What came from that was over designed racking systems. A comparison was done between previous racking system designs and the racking systems selected by the program. This revealed that previous designs were over-designed with bracing that was not required.

The spreadsheet ensures that the scantlings selected are adequate without being overly conservative. Pipe Rack Spreadsheet Summary Sheet

Spreadsheet Summary

The racksf.xls spreadsheet was developed to assist in the selection of pipe racks scantlings for a variety of situations. Although many configurations are covered, some unique installations will have to be analyzed separately. The sheet consists of an input box, output box, a scantling chart, calculation section and several drawings. An attempt was made to create a product that is user friendly and easily updated if different criteria is to be used. The following is a line by line description of the spreadsheet.

INPUT BOX

Allowable Stress (psi) - This is the user defined maximum allowable stress in the pipe rack scantlings. This value is based on the scantling material. A commonly used value for steel is 34000 psi. Adjustments in this figure can produce varying factors of safety. (i.e. 17000 psi would create a ‘factor of safety’ of 2)

# of Pipes (#) - This value can range any where from 1 to 15 pipes. If necessary, the chart can be altered to accommodate additional pipes. This would require adding additional rows to the pipe charts in both the input box and calculation box. The total weight line in the calculation box would also change to reflect the added rows. In a double tier situation, it would be necessary to run two different calculations. The first calculation would be for the outer tiers rack and legs. The second calculation would be for the inner tier rack and legs. For the second calculation it would be necessary to add the weight of the outer tier as an additional weight.

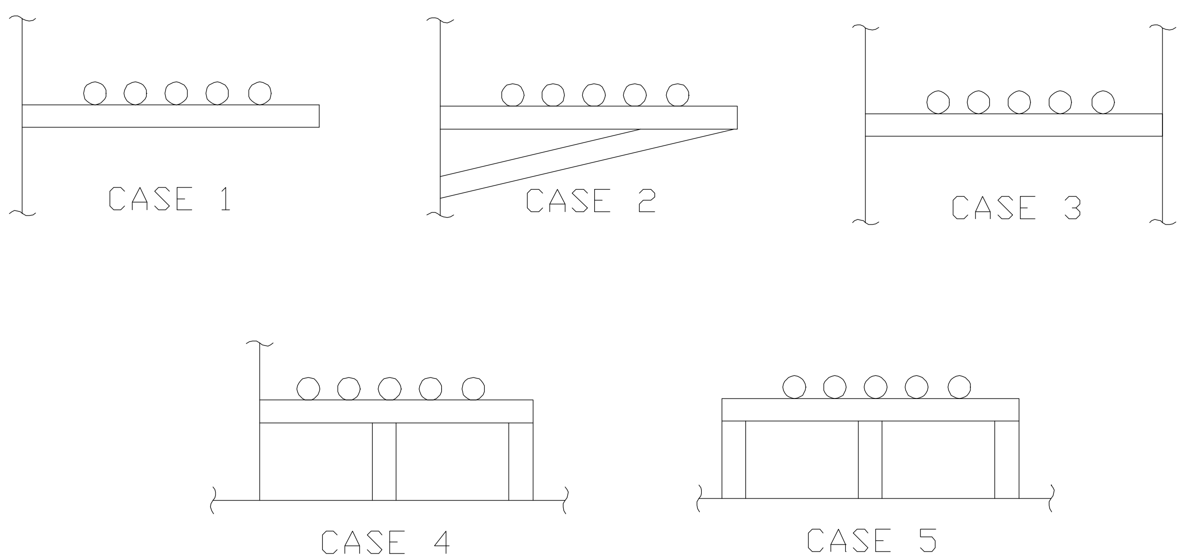
Standoff (in) - This is the distance the pipes are away from the structure or simply the leg length.

Length of Rack (in) - This is the width of the rack or the length of the pipe supporting scantling. In the cantilever case, there is only rack and no leg.

Gz, Gx, Gy - These are G force inputs to the to the pipe rack. The G-load chart indicates proper orientations. The values are a function of location in the ship and ships motions.

# of Legs (#) - Simply the number of legs the rack has. This does not include attachments to ship structure.

# of Structural Attachments (#) - Simply the number of attachments to the ship structure. This value should not include legs.



THIS PAGE LEFT BLANK FOR INSERTION OF SCANTLING SELECTION SPREADSHEET (INPUT -- see additional download)

AVAILABLE SCANTLINGS

	RACK	LEG		RACK	LEG
ANGLE	SM	SM	CHANNELS	SM	SM
1 X 1 X 1/8	N/A	N/A	RTD1.624X.625X14GA	N/A	N/A
RTD 12 GA ANGLE	N/A	N/A	1-1/4 X 1/2 X 1.0 #	N/A	N/A
1 X 1 X 1/4	N/A	N/A	RTD1.624X.625X3/16	N/A	N/A
1-1/4 X 1-1/4 X 3/16	N/A	N/A	2 X 1 X 2.32 #	N/A	N/A
1-1/2 X 1-1/2 X 1/8	N/A	N/A	3 X 1-5/8 X 6.0 #	N/A	N/A
RTD 3/16 ANGLE	N/A	N/A	4 X 1-5/8 X 7.25 #	N/A	N/A
1-1/2 X 1-1/2 X 1/4	N/A	N/A	5 X 1-3/4 X 9.0 #	N/A	N/A
2 X 2 X 1/4	N/A	N/A	6 X 2 X 10.5 #	N/A	N/A
2 X 2 X 3/8	N/A	N/A	8 X 2-1/4 X 11.5 #	8.140	N/A
2-1/2 X 2-1/2 X 5/16	N/A	N/A	6 X 3-1/2 X 15.3 #	8.368	N/A
3 X 3 X 1/4	N/A	N/A	10 X 1-1/2 X 8.4 #	8.909	N/A
3 X 3 X 3/8	N/A	N/A	8 X 3 X 18.7 #	11.000	N/A
4 X 3 X 1/4	N/A	N/A	9 X 2-1/2 X 15.0 #	11.300	N/A
4 X 3-1/2 X 5/16	N/A	N/A	12 X 1-1/2 X 10.6 #	13.715	13.715
4 X 3 X 3/8	N/A	N/A	10 X 3-1/2 X 25.3 #	18.200	18.200
5 X 3-1/2 X 5/16	N/A	N/A	12 X 3 X 20.7 #	21.500	21.500
4 X 4 X 1/2	N/A	N/A	13 X 4 X 35.0 #	37.106	37.106
5 X 3-1/2 X 3/8	N/A	N/A			
6 X 4 X 5/16	N/A	N/A			
6 X 3-1/2 X 3/8	N/A	N/A			
6 X 4 X 3/8	N/A	N/A			
6 X 4 X ½	N/A	N/A			
7 X 4 X 3/8	N/A	N/A			
7 X 4 X ½	5.810	N/A			
8 X 4 X ½	7.490	N/A			
9 X 4 X ½	9.340	N/A			

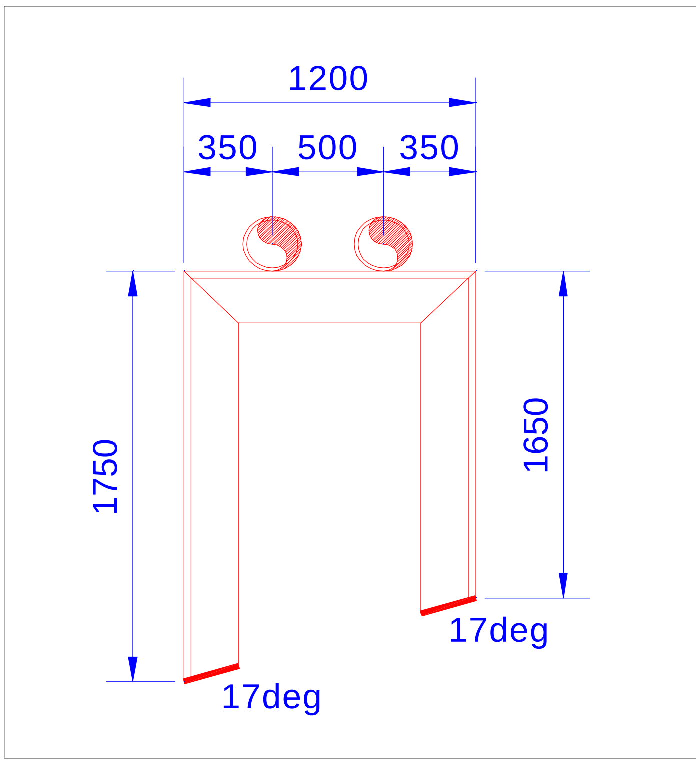
	LEG
PIPE	SM
1" SCH 80	N/A
1-1/2" SCH 80	N/A
2" SCH 80	N/A
2-1/2" SCH 80	N/A
3" SCH 80	N/A
4" SCH 80	N/A
5" SCH 80	N/A
6" SCH 80	N/A
8" SCH 80	24.514
10" SCH 80	45.552
12" SCH 80	74.526
14" SCH 80	98.188

OUTPUT TANKER MAIN RACK	
RACK DATA	
RACK LENGTH (IN)	216
RACK REQD SM (IN^3)	5.533
ANGLE	7 X 4 X 1/2
ANGLE SM (IN^3)	5.810
ANGLE I (IN^4)	26.7
ANGLE FREQ (HZ)	1.89
CHANNEL	8 X 2-1/4 X 11.5 #
CHANNEL SM (IN^3)	8.140
CHANNEL I (IN^4)	32.56
CHANNEL FREQ (HZ)	2.09
LEG DATA	
LEG LENGTH (IN)	82.00
LEG REQD SM	12.603
ANGLE	#N/A
ANGLE SM (IN^3)	0.000
ANGLE I (IN^4)	#N/A
ANGLE FREQ (HZ)	#N/A
CHANNEL	12 X 1-1/2 X 10.6 #
CHANNEL SM (IN^3)	13.715
CHANNEL I (IN^4)	82.29
CHANNEL FREQ (HZ)	3.54
PIPE	8" SCH 80
PIPE SM (IN^3)	24.514
PIPE (IN^4)	105.716
PIPE FREQ (HZ)	4.02

APPLICATION OF PARAMETERS TO MODEL

Based on the parameters validated by the Engineering Analysis Spreadsheet, a model of the foundation for the Equipment Installation is created and/or applicable dimensions applied to that model. At this point, the Equipment Installation foundation has become a product model, such that Production Information attributes are included as part of the model. This will enable automated Production Information to be created. From this point, similar repeatable products can be assigned to appropriate work stations or other facilities used by the shipyard for construction and assembly.

Sketch of pipe support



Material List		
L#	100*100*10	4450 mm
UB	UB1_200	2 ea
UN	UN1_200	4 ea
Paint	U2	
Position	X	FR67+500
	Y	700(STBD)
	Z	1500 ABL
Weight	325 Kg	
Name	ES_PPSPT_B01_005	

FINAL DESIGN

At this point, the design team should have a valid product model to apply to the final design. The model will provide the information necessary to provide production information. The advantages now included as an integral part of the production information are as follows:

- Automated Layout of Hangers and Foundations

The final arrangement model will provide location information for the layout of hangers and foundations. The location points will be included in the NC information that goes to the steel plate burning machines. The burning machines are capable of marking locating point on the steel. These locating marks can then be used to install the hangers and foundations. The method of placing the locating points will be dependent on the materials to be installed.

For example, in the case of hangers and foundations where weld pads are required, such as on the weather deck for a tanker, the weld pads are designed to have standard markings or notches that are used to line up with the location markings created with the automated burning machines.

- Automated Hanger and Foundation Sketches

  The model will also have the information to provide shop information to fabricate hangers and foundations with a high degree of accuracy. This automated foundation sketching will be similar to pipe spooling software and applications already being used.

  The production information created from the intelligent model will have the following attributes:

  - Automated material lists

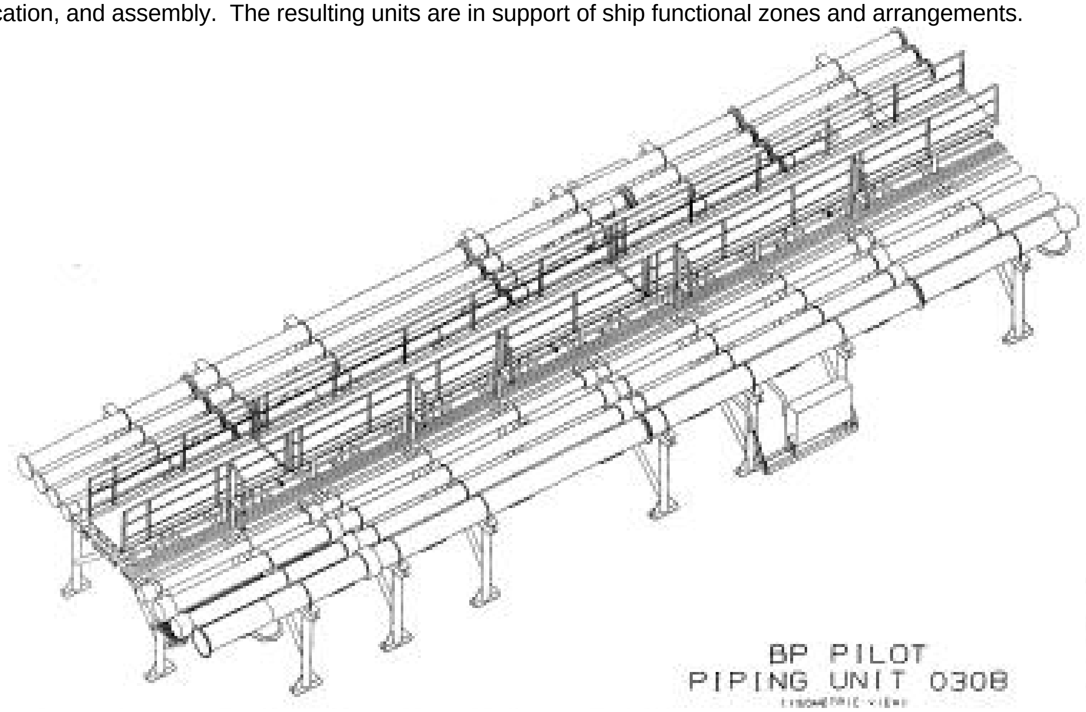
    Each sketch will have all the materials and attributes of the model(s) to automatically produce a parts list relative to each sketch.

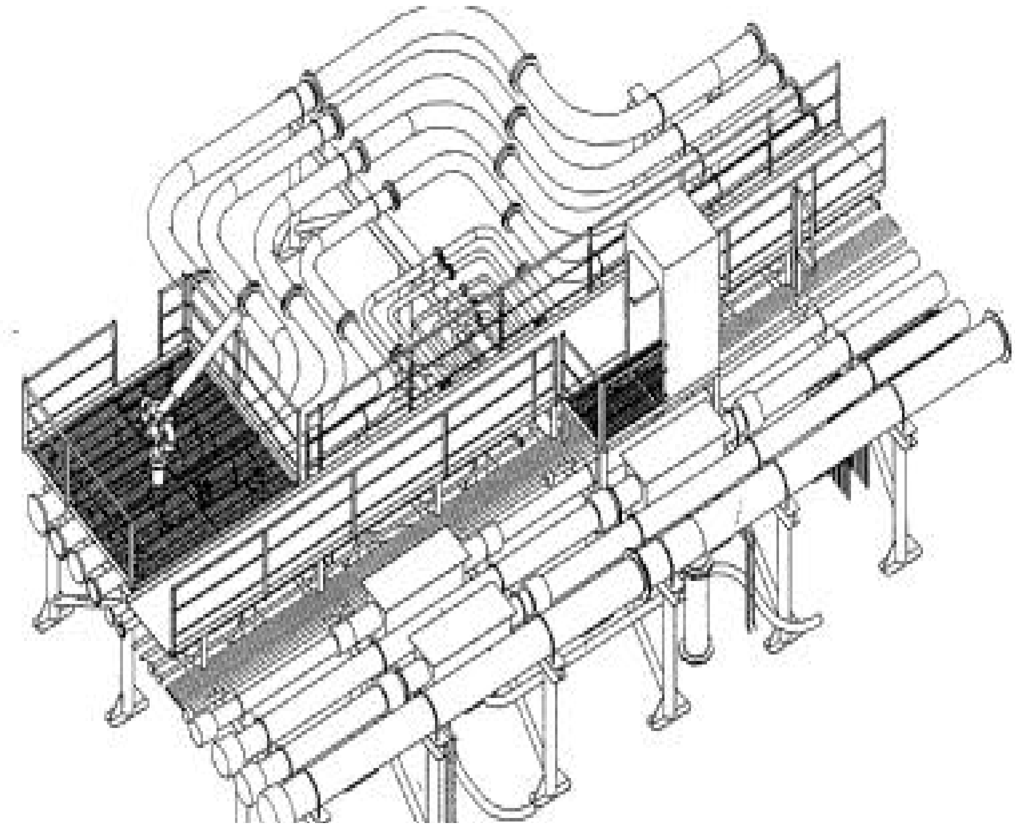
  - Neat cutting of hangers

    Materials used for hangers, such as steel angle, can be cut to accurate dimensions.

  This will eliminate "cut to suit" operations in the field. In order to increase throughput in the field or on the ship, the focus for field operations will be installation rather than fabrication. Fabrication is best performed in shops under controlled conditions and proper tools and facilities.

Finally, the product models can be managed hierarchically to support interim product development, design, planning, fabrication, and assembly. The resulting units are in support of ship functional zones and arrangements.





NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATION

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP 0537 PROJECT SP-6-95-2
SECTION NOS. 9 AND 10 — REVIEW AND APPROVAL PROCESS

PRINCIPAL INVESTIGATOR:

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ADDITIONAL INVESTIGATOR:

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VIBTECH, INC.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

9. REVIEW AND APPROVAL PROCESS

OVERVIEW

Current shipyard standards for equipment and system installation standards are almost universally based on design standards developed for U.S. Navy Warships from the 1950's through to the 1970's. The practice in warship design has been to base the designs for new vessels on the designs developed for old vessels. As a result very little change in manufacturing or shipyard installation practices has occurred in warship design. On the other hand, there has been significant pressure to improve productivity on the commercial side of the house, in the interest of becoming globally competitive. World class shipbuilding competitiveness is based on acquiring and implementing state-of-the-art shipyard process technology, achieving high productivity in a motivated workforce within the framework of a high performance organizational structure and innovative ship design technology that will provide a technological edge of superiority over world class competition.

Techniques for the design of equipment and system installation standards are embodied in the ship design reference material for vessels that date back to the 1950's. These standards were developed to be used on vessels whose primary and secondary structures were developed based on "deterministically" developed loads for the hull girder and primary structural system members. Traditional methods for developing ship hull scantlings for the primary hull and secondary structures were based on stress loadings from still water bending moments for the primary structure and estimates for static loadings; i.e., dead and live loads on decks and flooding heads on bulkheads, for secondary structures. Deterministic approaches to characterizing the pseudo-static hull bending moment and shearing forces are found in almost every naval architecture text. The development of equipment and system installation standards has been based on the use of traditional hull loadings to satisfy strength considerations. However, it is important in the development of an innovative approach to equipment and system installation standards, to determine the effects of both strength and fatigue performance of the new standards in their attachments to hull structure.

It is very difficult for the ship design community to abandon empirically based designs that have been proven through years of successful application, especially since maritime insurers place a great deal of importance on risk avoidance. With the emphasis being placed today on efficient hull structures, the notion of cumulative damage occurring to the ships structure demands a statistical approach to the determination of ship hull primary and secondary loadings as a function of time (note: the use of high strength steel to reduce hull structural weight on dry bulk ships that is resulting in short lives for those vessels, demonstrates that vessels designed for strength alone may be susceptible to other forms of damage). As new hull designs emerge and special considerations for cost effective construction are investigated in the design process, probability based designs will provide the potential of developing a more rational approach to the determination of ship scantlings and innovative approaches to the development of equipment and system installation standards. Industry standards that are based exclusively on empirically developed designs will be obsolete as a basis for establishing standards that are both cost effective and reliable.

While is essential to consider strength when developing industry standards for equipment and system installation criteria and details, cost effective equipment and system design and hull attachment standards must necessarily address fatigue. A rational process for design innovation will include a first principles approach to engineering and testing to validate the design.

FIRST PRINCIPLES ENGINEERING AND TESTING TO SUPPORT INNOVATIVE ATTACHMENT METHODS

In an effort to employ probabilistic techniques as a basis for developing foundations for advanced combatants, a combined experimental and analytical investigation was performed by Vibtech Inc. and Lehigh University under the stewardship of Dr. Robert Dexter and with the sponsorship of the Naval Surface Warfare Center - Carderock Division, to achieve proper and cost effective foundation integration with the Advanced Double Hull (ADH), see References 1, 2 and 3. Based on these investigations, it was determined that in certain instances, foundations can be landed on deck and bulkhead plating

without the use of backup structure. See *Figure 9-1*. for a conservative application of these findings. It was determined that the general specifications for ships could be revised accordingly.

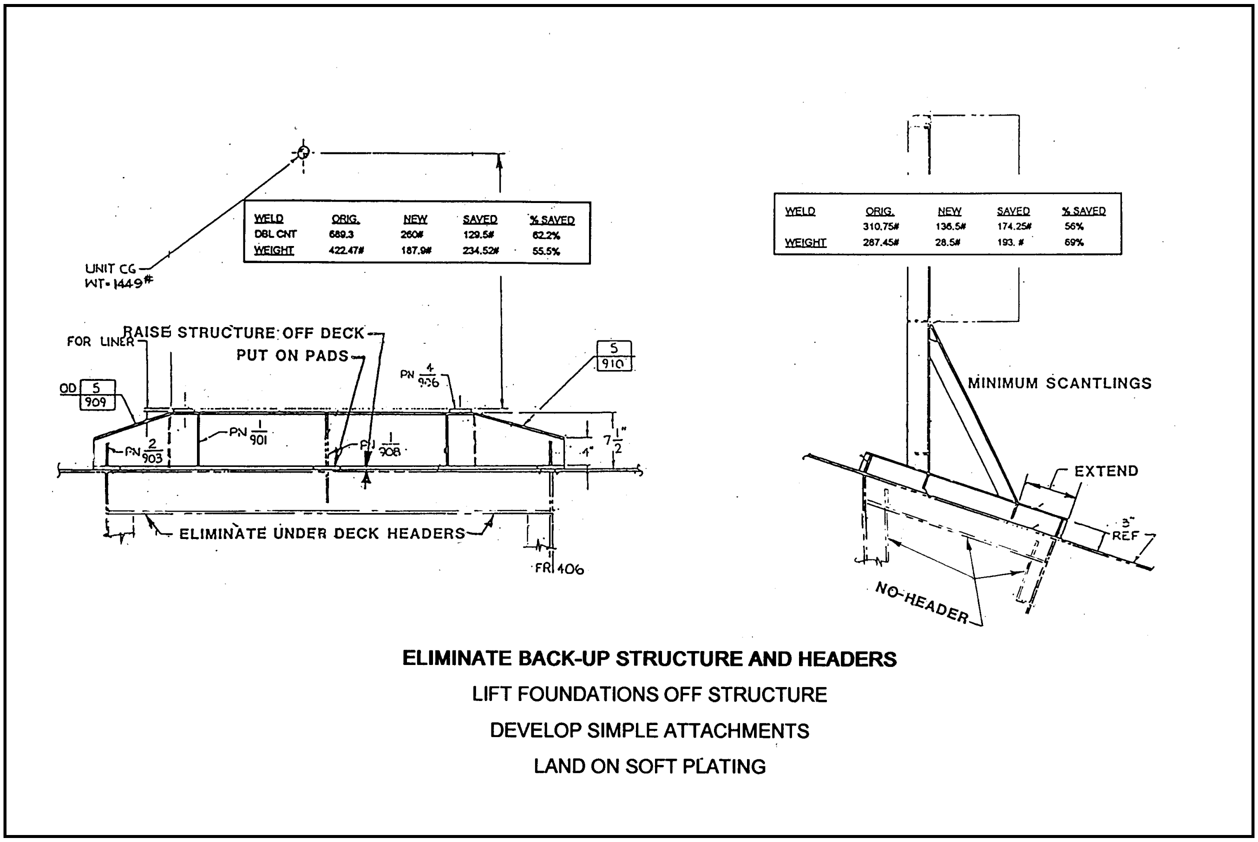

Figure 9-1 — Eliminate Back Up Structure and Headers

FIRST PRINCIPLES ENGINEERING APPROACH

The foundations investigated were based on Vibtech's family of standard designs comprised of frames, trusses and grillages and fabricated out of angle sections. This family of designs, (or Standards) described elsewhere in the report, was developed over a period of years based on a statistical compilation of foundations designs that were extracted from a number of ship design programs. See *Figure 9-1* for a characterization of the statistics for this foundation database.

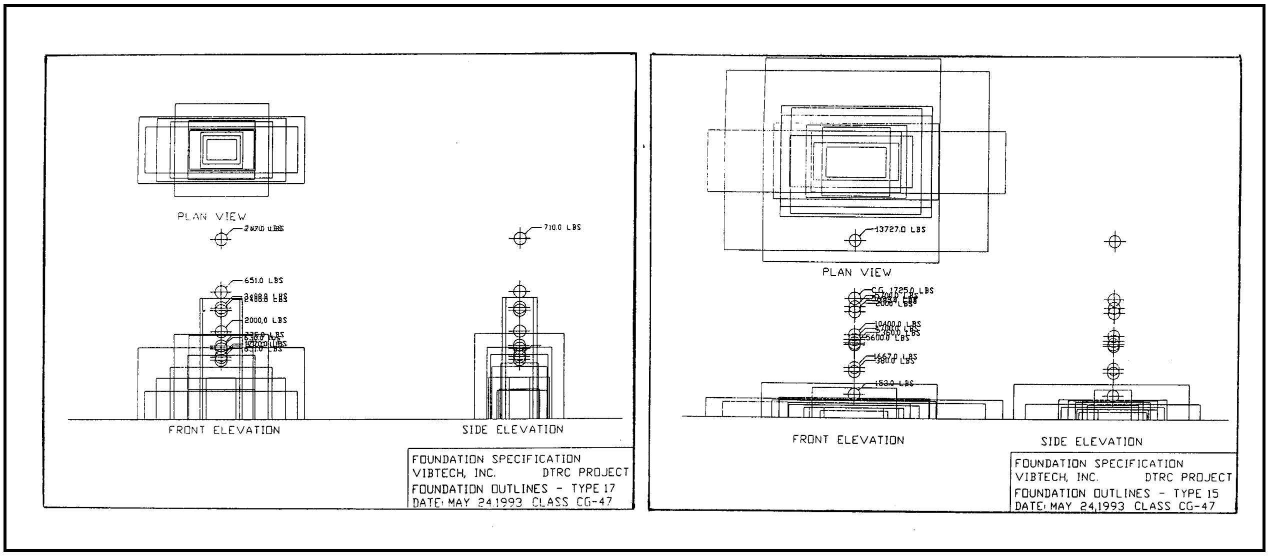

Figure 9-1 — Characterization of Foundation Database

Since ship structures are designed for both primary and significant secondary loads, there is considerable redundancy in the strength of the structure in way of most equipment and system attachments to ship structure, based on the statistics developed from previous ship design efforts. The investigations conducted under the NSWC-CD program evaluated the strength margins to see if it were possible to land on soft plate and satisfy strength, fatigue, shock and vibration requirements. Most important, for commercial ships, after strength and vibration considerations were satisfied, is to make sure that fatigue performance for the innovative attachments are satisfied. *Figure 9-2* shows that landing on unsupported plate introduces eccentricity in the attachment detail. This eccentricity causes intense local out-of plane distortion and associated stresses between the girder and the leg of the foundation attachment. Because the stress ranges, which occur locally in the eccentric details, would be much larger than the stress in the aligned details for the same loading, the resistance to cracking is significantly less for these eccentric details. However, Reference 1 and 2 point out that stress ranges from machinery and seaway loadings are very small. Therefore, satisfactory fatigue life is achievable despite the large eccentricity in the attachment detail.

During the study performed with NSWC-CD, parametric analyses were performed for over 100 candidate foundations to determine the allowable equipment mass in accord with strength, shock, vibration and fatigue performance requirements. Angle attachments were welded directly to soft plate without pads or backup structure. The tolerance for the attachment eccentricity between the deck primary structure and the attachment was up to 60 mm. Other locations were evaluated to include one thickness offset, 85 mm offset and a mid span panel location, See *Figure 9-2*.

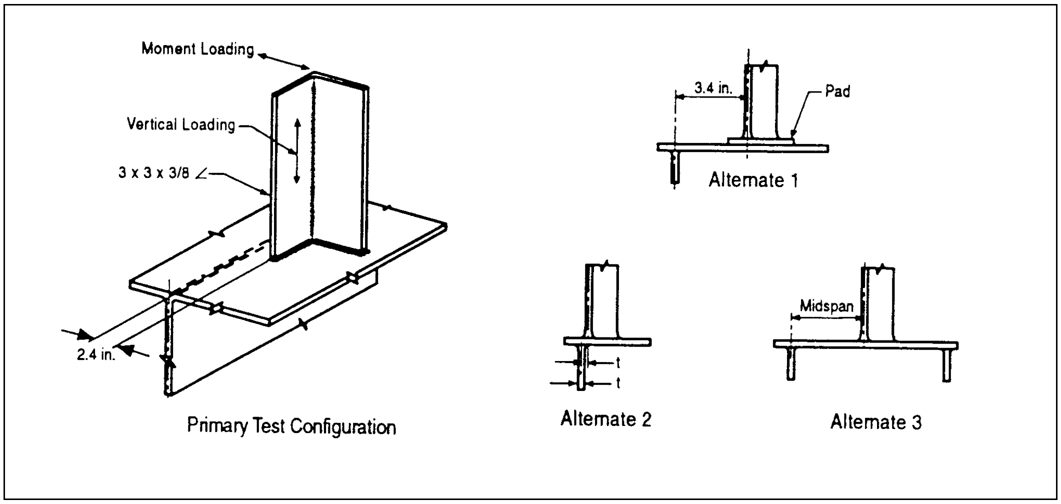

Figure 9-2 — Foundation Attachment Details

A significant part of the project was the finite element modeling of the attachment details and correlation of the calculated stresses with the static stress data. Stresses were obtained from the static test of each fatigue test specimen, at what were considered to be significant stress locations. A total of 52 standard locations were identified. The FEA models were constructed such that for the most part a node was located at these standard locations. This allowed direct comparison between stress readings from the FEA models at the nodes with the test specimen measurements. The correlation process required the data from both the specimens testing and the FEA model to be organized into a format that would permit comparison of the geometry, load case, gage locations and proper equivalent units. The results were then compared by calculating the variation between the FEA results and the average of the test results, and by plotting the various stress readings and calculations for a given geometry and loading on the same axes. The preliminary test configuration strain gage data correlated within 5% of the FEA model results. While not all configurations or locations exhibited such good correlation, the FEA results fall within the range of values obtained from the static testing. We found that we had to tailor the FEA model to the exact physical measurements of the test specimen in order to obtain good correlation. Using nominal scantling dimensions in the FEA model resulted in significant variations from the tested results. Correlation at this level of detail establishes the finite element method as a valuable design tool that supports the use of details such as those used in *Figure 9-3* and can be used to develop more innovative attachment methods.

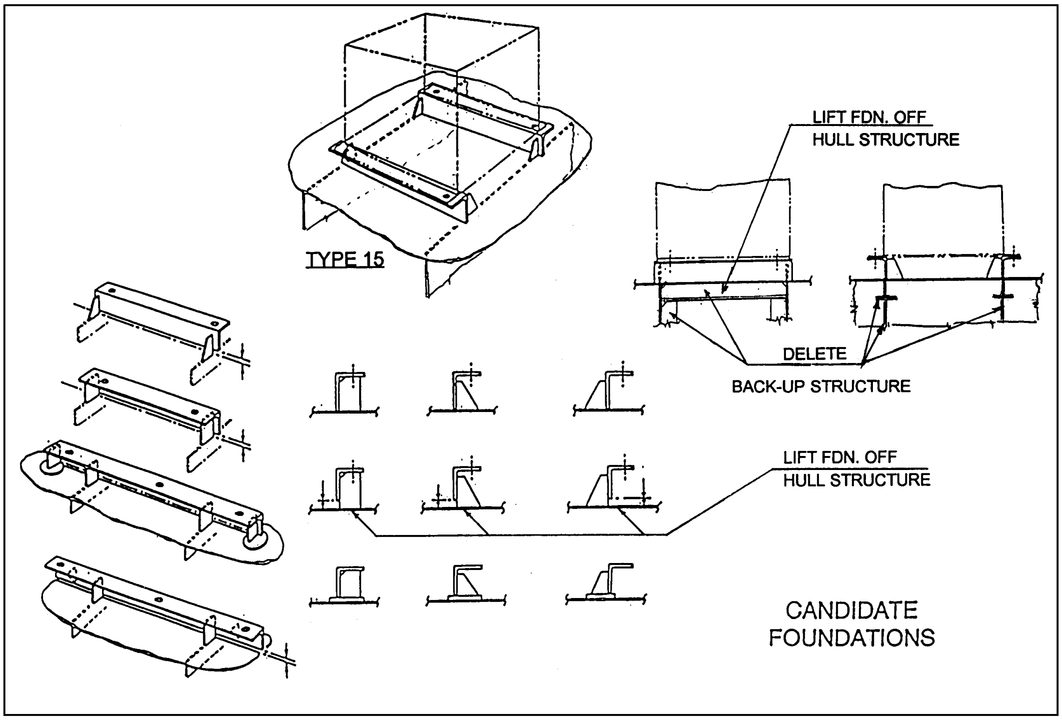

Figure 9-3 — Candidate Foundations

Reference 2 indicated that the traditional approach to ship structural design requires that the foundation attachments, i.e., the equipment and system installation attachments, land precisely over the internal girders or other primary strength members with an eccentricity of less than one plate thickness. Eliminating the need for backup structure and allowing foundations to land on unsupported plate will greatly increase productivity, save weight and reduce costs.

FATIGUE TESTING TO SUPPORT DEVELOPMENT OF INNOVATIVE ATTACHMENT DETAILS

Full scale fatigue tests were conducted to verify the fatigue performance of these eccentric attachments. Cyclic axial and bending loads were applied to angle sections which were fillet welded normal to the soft plating of the hull at various eccentricities relative to the underlying primary hull longitudinal web structure. The hot-spot stress range, See *Figure 9-1*, measured with a strain gage placed adjacent to the weld toe, was plotted with the number of cycles to through thickness cracking.

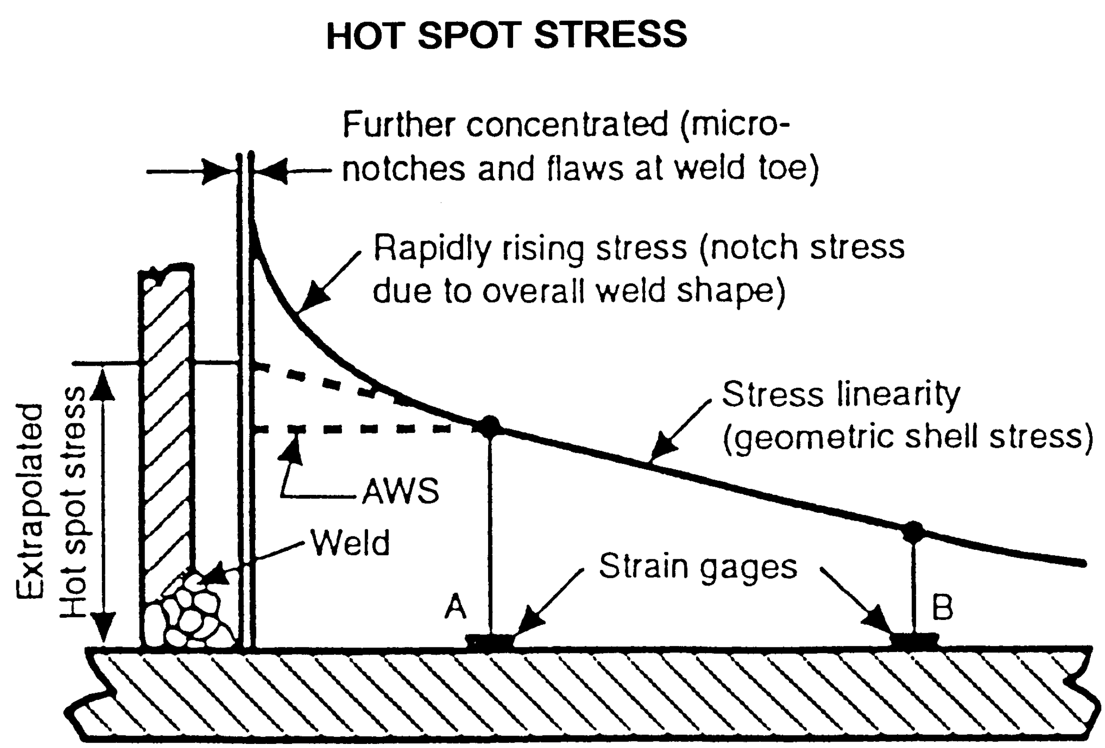

Figure 9-1 — Hot Spot Stress

The hot-spot stress, correlated reasonably well with the FEA foundation models, See *Figure 9-2*, that were tailored to take into account the attachment to the structure and the natural variability of the geometry. The "Hot-Spot" stress uses only the geometric stress in the design procedure, excluding the local stress concentration that is highly variable and difficult to quantify. The point along the weld toe at which the geometric stress is maximum is known as the "Hot-Spot". Assuming that there are no gross flaws elsewhere along the weld toe, it is expected that the cracking will start at this "Hot-Spot", See Reference 3.

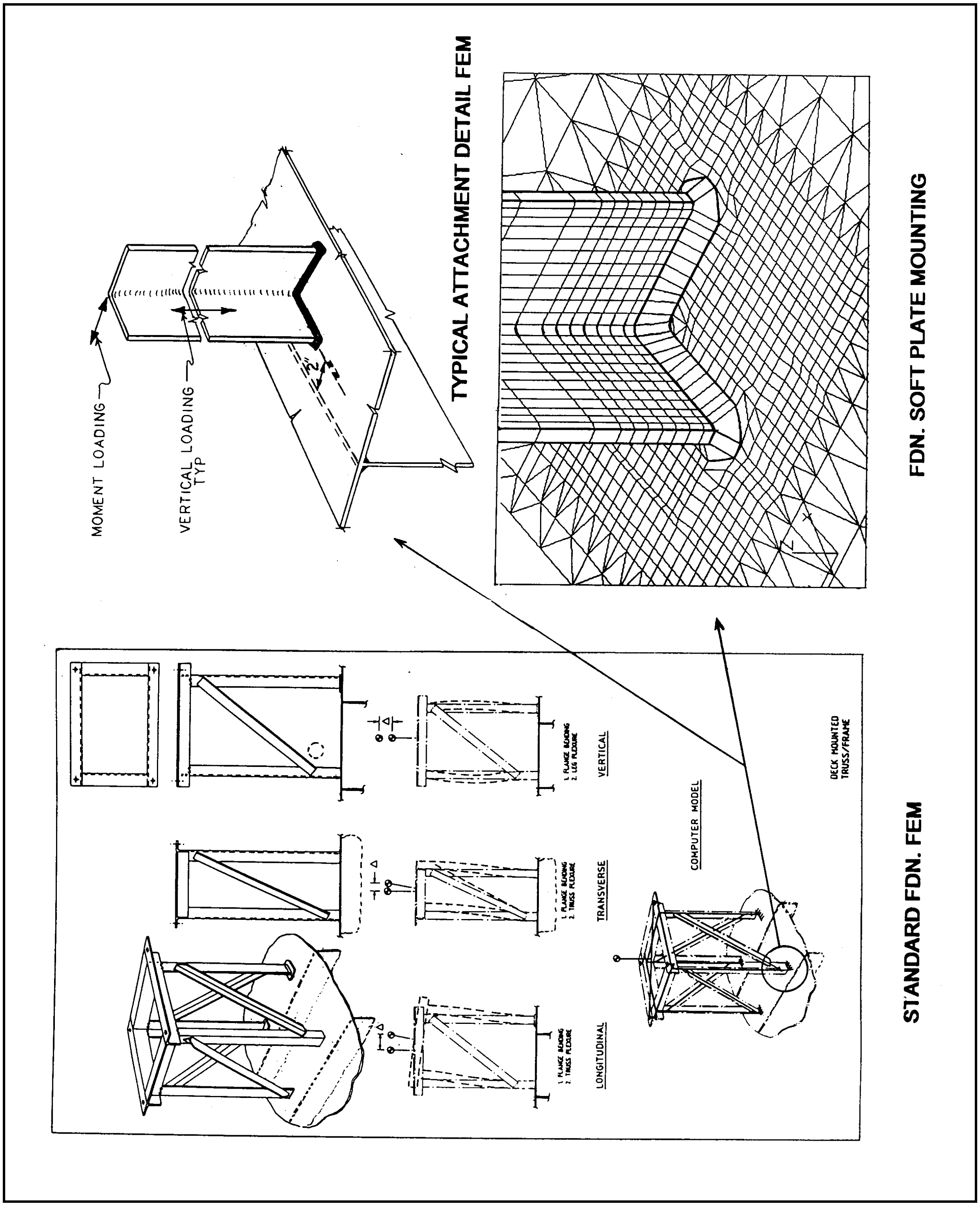

Figure 9-2 — Typical Attachment Detail FEM

Full scale tests were performed to characterize the fatigue resistance of lightweight foundation attachments with no backup structure and large eccentricity. The tests are fully described in Reference 1 and 2. Constant amplitude fatigue experiments were conducted on A572 Grade 50 angle sections (75mm x 75 mm x 10mm) with various attachment details as shown in *Figure 9-2*, Set 1 and 4. The angles were attached to 26 full scale box sections made up of 10 mm thick A572 Grade 50 steel plate. The minimum specified yield strength for A572 Grade 50 plate and angle sections is 350 MPa (51ksi). Fillet welds were made using a Carbon-Dioxide gas shielded flux-cored welding (FCAW) process.

A primary configuration was subject to three types of constant-amplitude loadings to assess its fatigue resistance. The loadings consisted of a force applied along the axis of the angle (Axial test), a force lateral to the angle (Bending test), and a simultaneous loading axial to the angle and in the plane of the top plate of the box (Biaxial test). Three "Alternate" details were tested in axial loading only to examine the influence of eccentricity to the web.

The test matrix for each configuration was a factorial design with minimum hot-spot stress and stress range as the main control variables. Tests were performed in load control using computer-controlled servo hydraulic actuators. Hot-spot strain was measured using a 3 mm gage placed 5 mm from the weld toe. Minimum stress levels were such that the details were loaded positively as well as reversed into the negative or compression region. More than sixty, (60), details were tested. Failure was defined as a through thickness crack. Crack behavior and hot-spot stresses are discussed in full in References 1,2 and 3. However, all the configurations, except alternate 2, exhibited cracking of the toe of the fillet weld attaching the angle to the plate.

In this study the AASHTO category C curve was chosen as the base-line curve or S-N curve. This curve represents the fatigue strength of a transverse weld when failure occurs for a crack at the weld toe. The "local" SCF due to the weld toe and weld discontinuities is built into the C curve. Category C is the appropriate nominal stress design S-N curve for a transverse groove weld in a plate with a uniform membrane stress. In other words the Category C curve represents a weld with a "global" stress concentration factor (SCF) of one. The hot-spot method includes the "global" SCF in the analysis. Using the ASSHTO Category C curve, a link is provided between the hot-spot approach and the nominal stress approach. The Category C curve is widely accepted in the U.S., (it is the same as the AISC or AWS Category C curve). It has a rationally determined and realistic slope and constant amplitude fatigue limit. The data from the various configurations plot in the same scatter band just above the AASHTO Category C fatigue design curve, See *Figure 9-3*. The lower bound plots directly on the Category C curve if a slope of -3 is imposed on the regression analysis. Though there is a wide range of scatter, especially in the axial data, the individual means of each set of data fall near the mean of all the data combined. Therefore, the results of the tests are assumed to be of the same population.

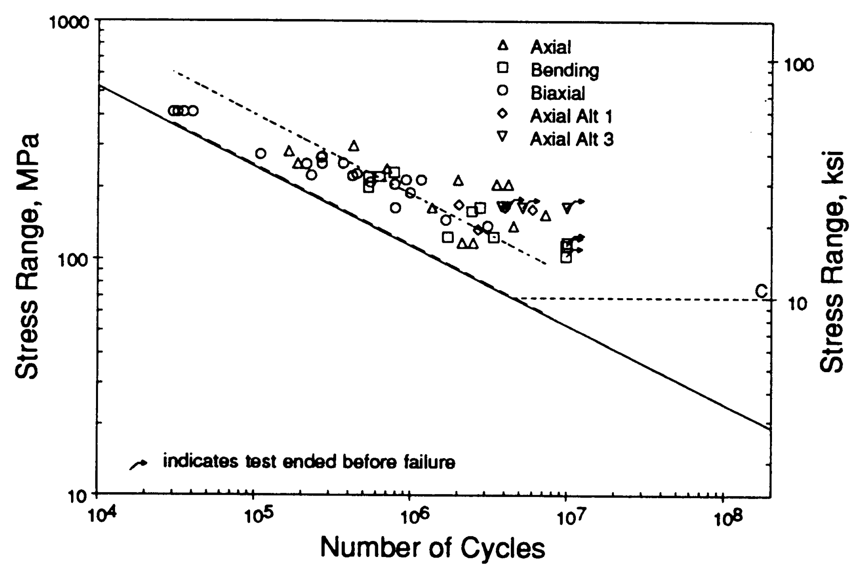

FIGURE 14 Compilation of all data plotted with respect to the AASHTO C curve (excluding Alternate 2).

Figure 9-3 — Fatigue Test Data

It is important to note that, though the S-N data for all configurations shown in *Figure 9-3* are evaluated with respect to the Category C curve, the load varies with eccentricity to attain the same stress range in each configuration. In other words, the more eccentric the detail, the less load is required to induce a given hot-spot stress. Therefore, each configuration was ranked with respect to a stress concentration factor defined as the ratio of the hot-spot stress to the nominal stress in the angle (see *Table 9-1*). If a critical hot-spot stress range governs the design, the allowable equipment mass for a given foundation will be inversely proportional to the SCF.

LOADINGS	DETAIL	SCF
AXIAL		
	PRIMARY	14.3
	ALTERNATE 1	13.2
	ALTERNATE 2	2.7
	ALTERNATE 3	23.0
BENDING		2.2
BIAXIAL		
	AXIAL STRESS	14.3
	IN-PLANE STRESS	

Table 9-1 — Stress Concentration Factors Relating Nominal Stress to Hot Spot Stress

The SCF ranges from 2,7 for eccentricities equal to the 0.38 in (10 mm) thickness of the web girder (alternate 2), to 14 at 2.4 inches (60 mm) eccentricity (Primary Detail) and then to about 23 if the attachment is located at mid-panel (Alternate 3) i.e., about 18 inches (457 mm) eccentricity. The pad in Alternate 1 distributed the stress along the plate more evenly and therefore had a lower SCF than the primary detail despite the increased eccentricity. The SCF of Alternate 2 (one thickness eccentricity) agreed well with a simple formula for a misaligned load carrying cruciform joint addressed in the American Bureau of Shipbuilding (ABS) Guide for Fatigue Assessment of Tankers.

Robert Dexter recommends that for fatigue analysis and design, the lifetime history of the stress ranges must be characterized for critical details. Consistent with most modern fatigue design recommendations, it is accepted that: 1) Miner's rule for cumulative damage is valid, and; 2) that the slope of the S-N curve is equal to 3.0 for all stress ranges. On this basis, an effective constant-amplitude stress range can be calculated which results in approximately the same fatigue damage for a given number of cycles as the same number of cycles of the variable-amplitude service history. The effective stress range is the cube root or the mean cube (RMC) of the variable stress ranges. The allowable effective RMC hot-spot stress range of 4 ksi (28 MPa) was determined by extrapolating the Category C curve to 100 million cycles, i.e., about thirty years.

The results of these fatigue tests showed that the fatigue resistance of details with varying eccentricity off the hull girder web can be assessed by using the hot-spot stress range at ¼ in. (5 mm) from the weld toe and the ASSHTO Category C design curve. The relative resistance of each configuration can be ranked using a SCF relating hot-spot and nominal stress.

CLASSIFICATION SOCIETY EVALUATION

The ABS Rules for Building and Classing Steel Vessels provides the required strength for the hull structure. The scantlings are based on the loadings and allowable stress criteria that provide designs that are generally adequate for the intended service. Typically, the rules develop the required section modulus for scantlings based on an evenly distributed design load factored into an equivalent head. Adjustments may be made for higher strength materials and even for concentrated loads such as container loadings or in some cases vehicle loadings. However, these requirements only deal with the development of the essential strength required for hull structure. The rules are appropriate for structure that exhibits good continuity, regular and well defined load paths and structural detailing that follows established "good" practice.

The ABS Rules offer no guidance for the design of structure where there are structural discontinuities or where there are concentrated cyclic loadings induced by foundations on local structure. These stresses may be concentrated on a few longitudinals or on deck or bulkhead plating rather than distributed evenly over the entire deck or bulkhead structure. The ABS rules only address strength with implicit good fatigue performance implied based on good design practice. However, ABS offers explicit guidance for fatigue design in the " Guide for the Fatigue Strength Assessment of Tankers".

Throughout their service life new ships will experience environmental loadings that will cause cyclic stress variations in structural members. Those variations can cause fatigue cracking in welded structural details if the details are inadequately designed. A fatigue assessment, supported as appropriate, by fatigue analysis and testing, should ensure that important structural members do not result in catastrophic failure. While fatigue critical locations have been identified for principle ship structural details, there is virtually no information to characterize the performance of secondary type structures such as equipment and system installation details.

The combination of concentrated loads and eccentricity of loading patterns may result in a probability for higher than normal stress patterns that may affect the fatigue life performance for such details. References 1 through 8 provide state-of-the-art information and the context within which ABS will approve special structural details. These references illustrate the fatigue performance of structural details, methods for analysis and testing of details, characterization and application of both static and dynamic loads, fatigue load characterization and proper application of "peak stress" and "hot-spot" stress analysis techniques used to assess fatigue performance.

Since foundations for equipment and system hanger attachments usually are regarded as minor structures, ABS has not been traditionally involved in assessment and approval of these type of structures, other than main machinery foundations that may form part of the principle hull structure. However, since part of the innovative methods considered for "Leapfrog Technologies to Standardize Equipment and System Installations" is to land lightweight equipment foundations and distributive system hangers on soft plating to simplify construction and reduce cost, it is considered appropriate to evaluate the fatigue performance of such details with appropriate techniques. We believe that substantial work has been performed to validate such an approach as provided in References 1, 2 and 3. Never the less, it is considered prudent to involve the regulatory agencies in such evaluations in order to achieve a consensus in support of such cost saving approaches.

The American Bureau of Shipping was asked to comment on the results of the FEA and Fatigue Testing study of hull equipment foundation attachments. Their positive comments are attached herewith in Appendix ? While ABS comments are qualitative and appear supportive of the general approach advocated herein. It will be incumbent on shipbuilders to evaluate new developments for equipment and system attachments on an individual basis in order to provide assurance that the approaches used will maintain proper hull integrity

Fatigue design procedures using a characterization of stress in way of structural details have been developed as a basis for fatigue analysis. Munse, Stambaugh, Park, Lawrence and Bea describe fatigue stresses in ship details as a consequence of probabilistic based design hull girder loading and resulting stresses, See References 4 through 8. Their methods take into account the overall configuration of the detail without modeling the explicit geometry of the weld detail. They have developed special S-N curves that define the permissible stress range (double amplitude) for use with their particular description of the detail.

ABS Comments On Foundation Analysis and Testing Program at Vibtech Inc. and Lehigh University sponsored by the Naval Surface Warfare Center – Carderock Division:

See the following letters:

Comments on Paper "Foundations for Advanced Double Hull Combatants", by J. Hopkinson, R.J. Dexter, and D. McAfee

Conunents by Y.K. Chen, ABS

9/11/98

The paper presents an extensive study, in both FEA and experiments, on the cost-effective design of lightweight foundations on the unidirectional double hull combatants with the consideration of shock, vibration, fatigue and ultimate strength. Some of my specific comments on the paper are given below:

I . It is interesting to note that as concluded by the study, foundation angles of lightweight equipment in most cases can be fillet welded directly to the inner bottom plating without pads or backup structure or aligning with bottom girders. Although the offsets of foundation legs from girder webs would significantly increase the stress concentrations at the weld toes, and decrease the fundamental natural frequency of the system, the study showed that the attachment details met the performance

requirements for most equipment weights with associated foundation types from the point of view of shock, vibration, fatigue and static strength. This is very useful for cost-effective design and installation of lightweight foundations on inner bottoms of the double hull ships.

2. Vibration is an important aspect of the foundation design. Because of the so-called "soft mounting" as a result of increasing offsets of leg attachment points from bottom girders, the fundamental natural frequency of the foundation system will definitely decrease, possibly lower than the 15 Hz called for by the CG-47 Specifications for avoiding possible resonance with propeller excitation. By simply increase the stiffness of the foundation structure, as suggested by the paper, may not be able to raise the frequency high enough to meet the requirements. However, this point may be easily proved by a further study in this regard using the simple frame models as shown in Figure 4, with varying stiffness for the boundary elements and the foundation structure.

3 For fatigue strength assessment of the leg attachments, it is true that the so-called "nominal stress approach" is difficult to apply in this case, and the "hot spot stress approach" is more appropriate. However, the discussions on E-curve for the nominal stress approach, C-curve for the hot spot approach and the expression of the high magnitude SCF (in the range of 13 to 23) may be misleading. Actually, the corresponding nominal stress for the measured hot spot stress (or calculated by FEA) near the weld toe on the inner bottom is the plating local bending stress (without the presence of the attachment) caused by local deformation due to leg loads, not the axial or bending stress in the leg. When using the leg axial or bending stress as the nominal stress, the SCF should really be compared to the hot spot stress at the upper weld toe on the leg itself. This is also the reason that the SCF found in bending is so much lower than the SCF in axial load, contrary to the well fact that SCF in bending is higher that SCF in axial load. However, the present expression of SCF is still a good measure of the hot spot stress at the lower weld toe on the attached plating caused by the axial stress in the leg, only that the ratio should not be considered as SCF to the leg axial stress. If the nominal stress approach needs to be used in this case for fatigue assessment, the nominal stress should be taken as the local bending stress on the inner bottom plating.

4. The so-called "hot spot stress" is determined by taking into account the stress concentration due to structural discontinuities and presence of attachments, but excluding the effects of welds. As a result, there is no difference for

the SCF so determined for the case with fillet welds and the case with full penetration welds. When using the hot spot stress approach in the fatigue assessment of the attachment details, the C-curve as used in the study would be used in both cases. What is the authors' opinion in dealing the two cases which are expected to have significantly different fatigue performance?

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DIVISION OF THE AMERICAN BUREAU OF SHIPPING

8 May 1995

AAM/ls P-11

Mr. John Hopkinson, President
Vibtech, Inc.
125 Steamboat Ave.,
Box 435
North Kingstown, RI 02852

Subject: ABS Comments to "Foundations for Advanced Double Hull Combatants" Dear Mr. Hopkinson:

We have your telefax of 27 February, 1995 submitting one (1) copy of the following technical paper:

Foundations for Advanced Double Hull Combatants

and requesting our comments. We have reviewed the work and find it to be a comprehensive study dealing with a neglected shipbuilding topic, equipment foundation design, and showing potential for the reduction of both time and cost when fabricating a vessel.

The basic theme of the paper is that, for certain lightweight prices of equipment, their supporting foundations can be landed directly on the cell structure of unidirectional, double hull vessels without the typical concerns of alignment with the main framing or providing supplemental back-up structure. We must advise that many of the equipment foundations which fit into this category would not, in themselves, be class items. However, the Bureau is generally interested in the foundation's attachment to the basic hull structure since the type of attachment proposed in your paper would typically be considered to be a "hard spot" where cracking of the structure could initiate.

We have considered the methodology used in the paper, that is, the use of finite element models (FEM) to analyze the equipment foundations and their attachments to the cellular ship's structure followed by full-scale or half-scale fatigue testing of the foundation to validate the results of the FEM to be both acceptable and commendable. It is not often that we see analytical studies verified and calibrated by physical testing.

The modes of failure checked in the analysis appear to verify that the foundations and the attachment to the cellular hull structure would be acceptable for strength, vibrations, fatigue, deflection, hull deflection induced loads, loads induced due to restraint by attached systems (e.g. piping), ship motions and slamming. The only loading which does not seem to have been considered is the case of an equipment foundation attached to a tank boundary and restrained by piping systems. When the tank is filled to the overflow or experiences internal pressure, the hydrostatic head pushes the tank boundary plate into foundation's attachment point - a classic "hard spot."

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Vibtech, lnc.
8 May 1995
Page 2

For practical application, we presume that some form of tabular breaking down of foundation types into grillages, frames and truss would have to be developed showing the permissible mass of equipment vs. the eccentricity of attachment of the foundation from the hull cellular structure. Also, the thickness of deck plating on which the foundation is mounted would have to be included. There could be some plate thicknesses where additional consideration is required.

We do not believe that foundations for *massive, vital or alignment sensitive* equipment should be landed on ship's structures without regard to the location of back-up support structure. Also, equipment foundations which are located such that they cannot be readily visually inspected and those which would require an extraordinary amount of system disassembly work to repair any problems should not use this method of attachment.

The potential owners of vessels should be made aware of the fact that lightweight equipment aboard their ships is being installed on foundations without back-up structure. They may be an objection to using this installation method aboard their vessels.

Your foundations study was undertaken for possible use aboard advanced double hull combatant vessels. However, it appears that the study could also be applied to conventionally framed cargo vessels.

An interesting additional finding in your analysis was the unexpected deflection behavior of the finite element model of the unidirectional double hull machinery space. This finding was passed along to our Advanced Analysis Group who have done their own analysis of a proposed new construction tanker which uses the unidirectional double hull framing system. They generally agree with your results.

We appreciate the opportunity to read and comment on your paper.

Very truly yours,

AMERICAN BUREAU OF SHIPPING Christopher J. Wiernicki, P.E.
Vice President of Engineering
Manager, Ship Engineering Department

References:

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NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

UNIVERSITY OF NEW ORLEANS SUBCONTRACT

NSRP PROJECT SP-6-95-2
FINAL REPORT

PRINCIPAL INVESTIGATOR:

DOMINIC BURNS
SENIOR ENGINEER
NATIONAL STEEL AND SHIPBUILDING COMPANY

ADDITIONAL INVESTIGATOR:

JOHN HOPKINSON
PRESIDENT
VIBTECH, INC.

UNIVERSITY OF NEW ORLEANS
NEW ORLEANS, LA 70148

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

This project was funded by the National Shipbuilding Research Program, Standards Panel (SP-6), chaired by Steve E. Laskey of Bath Iron Works. The SP-6 Panel is one of the Ship Production Committee Panels of the Society of Naval Architects and Marine Engineers (SNAME) which were established with the purpose of improving U.S. shipbuilding performance.

This final report is part of the Leapfrog Technology to Standardize Equipment and System Installations project. The project consists of a manual including ten deliverables, a complete set of standards for foundations and hangers, a scantling selection computer program using Microsoft Excel, and this final report.

LIMITATIONS AND DISCLAIMERS

ABSTRACT

Leapfrog Technology is defined within this project as a holistic, cost effective approach to combining and applying innovative yet simple products and processes concurrently throughout various departments including engineering, fabrication shops, and production stages of construction.

The present technology for designing, manufacturing, and installing equipment foundations and systems is labor intensive and is often on the critical path of ship construction. The lowest total installed costs will be achieved through the streamlining or elimination of these labor-intensive tasks.

This project will give the tools, products and approach necessary to minimize the completely installed costs for foundations and hangering systems in the form of a manual including ten deliverables, a complete set of standards for foundations and hangers, a scantling selection computer program using Microsoft Excel, and this final report.

1. INTRODUCTION

The objective of this manual is to develop a set of equipment and distributive system installation standards that result in the lowest possible installed cost. These standards are to be parametric in nature and lend themselves to inclusion into a product modeling system.

Traditionally the design of foundations and hangering systems was based on qualitative requirements that have been developed from what is known as the principles of good sound shipbuilding practices. Line organizations in most shipyards have been conditioned over the years to properly implement the specifications. The basis or rationale for much of the specifications has been lost over time. It is difficult to attempt to initiate changes in design to reduce costs when engineers and designers will not risk departing from traditional ways because they are fearful of violating unknown criteria. Guidance on designs provided by engineering management organizations usually instructs the designer/engineer to use designs developed on prior ships as a basis for new designs. In this way previous designs are perpetuated and little or no innovation is permitted in the development of new designs.

By applying leapfrog technology, which is innovative yet simple products and processes concurrently throughout all departments within the shipyard, significant reduction of man-hours and construction lead times can be achieved in the area of foundations and hangering systems.

2. ENGINEERING AND DESIGN

2.1. INTEGRATION OF ENGINEERING DESIGN AND ANALYTICAL TASKS

Traditionally, design and analytical tasks are performed separately where there is little or no interaction between the two. The ultimate goal to reduce and streamline engineering costs and cycle time would have the design and analytical tasks combined into an interactive environment, such as the 3-D computer model. Embedding spreadsheet calculations within the 3-D model would combine physical design with analytical computations. What normally are separate and sequential processes could become one parallel process performed by one individual. This would give the following benefits:

- Combining two sequential tasks into one parallel task.
- Reduction in engineering manpower and cycle time.
- Eliminates repetitive engineering calculations that need to be performed and reduces the chance of human error.

The ultimate scenario would be to have intelligent 3-D parametric objects (i.e., foundations, hangers, and racking systems) which would update automatically in response to a design change. For example, if a pipe rack had two additional 10-inch diameter pipes added to the racking system, the change in the model would trigger off calculations being performed in the background which would determine the new required scantlings to support the additional loading. This might then automatically change the racking system scantlings from a 2 x 2 x 1/4 to a 3 x 3 x 1/4 angle bar support within the 3-D model.

2.2. HANGERING SYSTEM SCANTLING SELECTION PROGRAM AND SPREADSHEETS

A second option to integrating engineering design and analytical tasks would be to have the scantling spreadsheet calculations and the 3-D model as separate entities. This second approach was chosen for this project because U.S. shipyards use a variety of 3-D modeling systems. Presently, various computer 3-D modeling companies are discussing the development of embedded expert systems into their 3-D modeling systems.

As part of this NSRP project, a scantling selection computer program has been developed using Microsoft Excel software. The outputs include spreadsheets that aid engineers and designers in determining the required hangering system scantling size for the most common scenarios on-board a ship. Spreadsheets have been developed for single run hangers, single run hangers with bracing, racking systems with legs and structural attachments, and goal post racking systems with variable number of legs. These scenarios can be calculated using different configurations. These include forward and aft runs supported horizontally, athwartship runs supported horizontally, vertical runs mounted to longitudinal, and athwartship bulkheads. These spreadsheets determine the minimum section modulus and defaults to the required scantling size. The scantling selection, which can be chosen, should reflect the raw material stock carried by the particular shipyard.

In the past there was no simple and consistent manner to determine scantling sizes, therefore, most racking systems were overdesigned, driving up the total installed costs. The spreadsheet ensures that the scantlings selected are adequate without being overly conservative Hanger Scantling Selection Spreadsheet Summary

The racks.xls spreadsheet was developed to assist in the selection of pipe racks scantlings for a variety of situations. Although many configurations are covered, some unique installations will have to be analyzed separately. The sheet consists of an input box, output box, a scantling chart, calculation section, and several drawings. An attempt was made to create a product that is user friendly and easily updated if different criteria is to be used. The following is a line by line description of the spreadsheet.

2.2.1.

Allowable Stress (psi) - This value represent the user defined maximum allowable stress in the pipe rack scantlings. This value is based on the scantling material. A commonly used value for steel is 34,000 psi. Adjustments to this value can produce varying factors of safety (i.e., 17,000 psi would create a factor of safety of 2)

# of Pipes (#) - This value represent the range of outfitting systems (pipes) on the rack. The rack outfitting systems can range anywhere from 1 to 15. If necessary, the chart can be altered to accommodate additional systems. This would require adding additional rows to the pipe charts in both the input box and calculation box. The total weight line in the calculation box would also change to reflect the added rows. In a double tier situation, it would be necessary to run two different calculations. The first calculation would be for the outer tiers rack and legs. The second calculation would be for the inner tier rack and legs. For the second calculation it would be necessary to add the weight of the outer tier as an additional weight.

Standoff (inches) This value represent the distance between the pipes and the hull structure or simply the leg length.

Length of Rack (inches) This value represents the width of the rack or the length of the pipe supporting the scantling. In the cantilever case, there is only rack and no leg.

Gz, Gx, Gy These values represents the G-force inputs to the to the pipe rack. The G-load chart indicates proper orientations. The values are a function of location in the ship and the ship s motion.

# of Legs (#) This value represent the number of rack legs. This value does not include attachments to the ship structure.

# of Structural Attachments (#) This value represent the number of attachments to the ship structure. This value should not include legs.

Spreadsheet Detailed Instructions - The manual of instructions for stud spreadsheets & scantling selection spreadsheet shows detailed instructions on using the spreadsheets in this project.

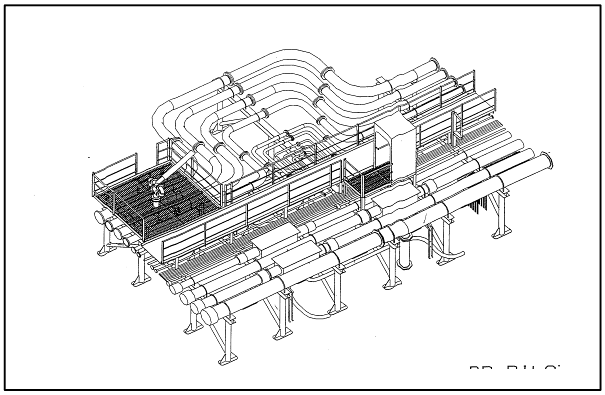
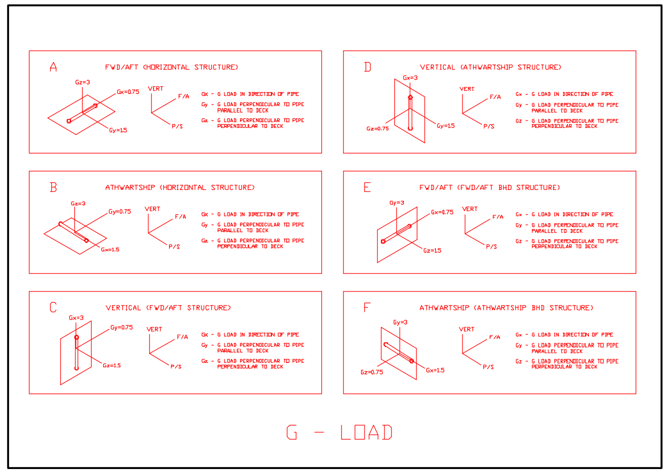


Figure 1 Typical Racking System Sample



INPUT RACKING SYSTEM DATA			**OUTFITTING SYSTEMS INPUT DATA**					
			PIPE INPUT	**PIPE WT/FT (WITH CONTENTS) (LBS/FT)**	**ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)**	**ACTUAL PIPE HANGER SPACING (FT)**	**START-UP FACTOR (MULTIPLIER**	**RACKING SYSTEMS**
ALLW. STRESS	34000	PSI	PIPE 1	201.80	0.00	13.00	1.00	18 IG
# OF PIPES	13	#	PIPE 2	102.10	0.00	13.00	1.00	12 CONDUIT
STANDOFF	82.00	IN	PIPE 3	102.10	0.00	13.00	1.00	12 CONDUIT
LENGTH OF RACK	216	IN	PIPE 4	5.12	0.00	6.50	1.00	2 AL01
G LOAD CASE (A-F)	A		PIPE 5	5.12	0.00	6.50	1.00	2 HV01
GZ	3.00	G'S	PIPE 6	5.12	0.00	6.50	1.00	2 HV01
GX	0.75	G'S	PIPE 7	10.80	0.00	6.50	1.00	3 DO
GY	1.50	G'S	PIPE 8	16.33	0.00	6.50	1.00	4 CO
NUMBER OF LEGS	4	#	PIPE 9	50.29	7.00	6.50	1.00	8 FO
# OF STR. ATTACH	0	#	PIPE 10	74.73	0.00	13.00	1.00	10 AF
INPUT CASE #	5	#	PIPE 11	74.73	7.00	13.00	1.00	10 FM
CASE 1	CANTILEVER		PIPE 12	102.10	7.00	13.00	1.00	12 TC
CASE 2	CANT W/ BRACE (STR ATT = 1)		PIPE 13	200.00	7.00	6.50	1.00	WALKWAY
CASE 3	2 STRUC ATT., NO LEGS		-	0.00	7.00	0.00	1.00	-
CASE 4	STRUC ATTS. PLUS LEGS		-	0.00	7.00	0.00	1.00	-
CASE 5	ONLY LEGS	OK						**

Table 1 Rack and Outfitting Input Data

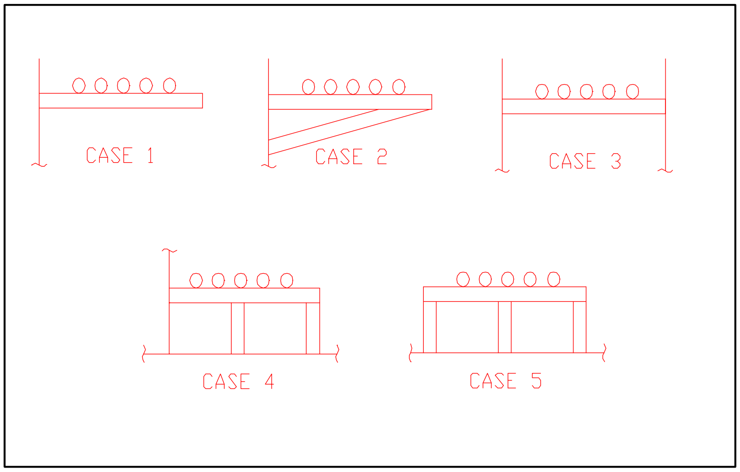


Figure 2 Five Input Case Scenerios

OUTPUT RACKING SYSTEM DATA			
RACK DATA		**LEG DATA**	
RACK LENGTH (IN)	216	LEG LENGTH (IN)	82.00
RACK REQD SM (IN^3)	5.533	LEG REQD SM	12.603
ANGLE	7X4X1/2	ANGLE	#N/A
ANGLE SM (IN^3)	5.810	ANGLE SM (IN^3)	0.000
ANGLE I (IN^4)	26.7	ANGLE I (IN^4)	#N/A
ANGLE FREQ (HZ)	1.89	ANGLE FREQ (HZ)	#N/A
CHANNEL	8X2-1/4X11.5#	CHANNEL	12X1-1/2X10.6#
CHANNEL SM (IN^3)	8.140	CHANNEL SM (IN^3)	13.715
CHANNEL I (IN^4)	32.56	CHANNEL I (IN^4)	82.29
CHANNEL FREQ (HZ)	2.09	CHANNEL FREQ (HZ)	3.54
		PIPE	8 SCH 80
		PIPE SM (IN^3)	24.514
		PIPE (IN^4)	105.716
		PIPE FREQ (HZ)	4.02

Table 2 Output Scantling Data

The tables above represent the minimum scantling requirements for the legs and rack to support the outfitting systems.

CALCULATIONS

	PIPE WT/FT (WITH CONTENTS) (LBS/FT)	ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)	ACTUAL PIPE HANGER SPACING (FT)	START-UP FACTOR (MULTIPLIER)	TOTAL WEIGHT (LBS)	RACK SCANTLINGS		LEG SCANTLINGS	
						RACK LENGTH	216.00	LEG LENGTH	82.00
PIPE 1	201.80	0.00	13.00	1.00	2623.4	TOTAL WEIGHT	10451.35	TOTAL WEIGHT	10451.35
PIPE 2	102.10	0.00	13.00	1.00	1327.3	W ZDIR (LBS)	10451.35	W VERT (LBS)	10451.35
PIPE 3	102.10	0.00	13.00	1.00	1327.3	W XDIR (LBS)	2612.84	W LONG (LBS)	2612.84
PIPE 4	5.12	0.00	6.50	1.00	33.3	W YDIR (LBS)	5225.68	W TRAN (LBS)	5225.68
PIPE 5	5.12	0.00	6.50	1.00	33.3	W ZDIR (LB/IN)	145.16		
PIPE 6	5.12	0.00	6.50	1.00	33.3	W XDIR (LB/IN)	36.29		
PIPE 7	10.80	0.00	6.50	1.00	70.2	W YDIR (LB/IN)	30.0072.58		
PIPE 8	16.33	0.00	6.50	1.00	106.1				
PIPE 9	50.29	7.00	6.50	1.00	326.9	CASE 1 Z MOMENT	188124.30		
PIPE 10	74.73	0.00	13.00	1.00	971.5	CASE 1 X MOMENT	94062.15		
PIPE 11	74.73	7.00	13.00	1.00	971.5	CASE 1 Y MOMENT	188124.30		
PIPE 12	102.10	7.00	13.00	1.00	1327.3	CASE 2 Z MOMENT	94062.15		
PIPE 13	200.00	7.00	6.50	1.00	1300.0	CASE 2 X MOMENT	47031.08		
N/A	0.00	7.00	0.00	1.00	0.0	CASE 2 Y MOMENT	94062.15		
N/A	0.00	7.00	0.00	1.00	0.0	CASE 3 X MOMENT	62708.10		
						CASE 3 Y MOMENT	15677.03		
						CASE 4 Z MOMENT	94062.15	CASE 4 Z MOMENT	214252.68
						CASE 4 X MOMENT	94062.15	CASE 4 X MOMENT	214252.68
						CASE 5 Z MOMENT	194062.15	CASE 5 Z MOMENT	428505.35
						CASE 5 X MOMENT	23515.54	CASE 5 X MOMENT	214252.68
						CASE 5 Y MOMENT	188124.30	CASE 5 Y MOMENT	428505.35
						RACK MOMENT ZDIR	94062.15	LEG MOMENT ZDIR	428505.35
						RACK MOMENT XDIR	23515.54	LEG MOMENT XDIR	214252.68
						RACK MOMENT YDIR	188124.30	LEG MOMENT	428505.35

CALCULATIONS									
	PIPE WT/FT (WITH CONTENTS) (LBS/FT)	**ADDITIONAL WEIGHT (VALVES, ETC.) (LBS.)**	**ACTUAL PIPE HANGER SPACING (FT)**	**START-UP FACTOR (MULTIPLIER)**	**TOTAL WEIGHT (LBS)**	**RACK SCANTLINGS**		**LEG SCANTLINGS**	
								YDIR	
						MAX RACK MOM	188124.30	MAX LEG MOM	428505.35
						RACK REQD SM	5.533	LEG REQD SM	12.603

Table 3 Scantling calculation data

AVAILABLE SCANTLINGS (WHICH MEET INPUT REQUIREMENTS)							
ANGLE	**RACK SM**	**LEG SM**	**CHANNELS**	**RACK SM**	**LEG SM**	**PIPE**	**LEG SM**
1 X 1 X 1/8	N/A	N/A	RTD1.624X.625X14 GA	N/A	N/A	1/2" SCH 80	N/A
RTD 12 GA ANGLE	N/A	N/A	1-1/4 X 1/2 X 1.0 #	N/A	N/A	3/4" SCH 80	N/A
1 X 1 X 1/4	N/A	N/A	RTD1.624X.625X3/16	N/A	N/A	1" SCH 80	N/A
1-1/4 X 1-1/4 X 3/16	N/A	N/A	2 X 1 X 2.32 #	N/A	N/A	1-1/4" SCH 80	N/A
1-1/2 X 1-1/2 X 1/8	N/A	N/A	3 X 1-5/8 X 6.0 #	N/A	N/A	1-1/2" SCH 80	N/A
RTD 3/16 ANGLE	N/A	N/A	4 X 1-5/8 X 7.25 #	N/A	N/A	2" SCH 80	N/A
1-1/2 X 1-1/2 X 1/4	N/A	N/A	5 X 1-3/4 X 9.0 #	N/A	N/A	2-1/2" SCH 80	N/A
2 X 2 X 1/4	N/A	N/A	6 X 2 X 10.5 #	N/A	N/A	3" SCH 80	N/A
2 X 2 X 3/8	N/A	N/A	8 X 2-1/4 X 11.5 #	8.140	N/A	4" SCH 80	N/A
2-1/2 X 2-1/2 X 5/16	N/A	N/A	6 X 3-1/2 X 15.3 #	8.368	N/A	5" SCH 80	N/A
3 X 3 X 1/4	N/A	N/A	10 X 1-1/2 X 8.4 #	8.909	N/A	6" SCH 80	N/A
3 X 3 X 3/8	N/A	N/A	8 X 3 X 18.7 #	11.000	N/A	8" SCH 80	25.514
4 X 3 X 1/4	N/A	N/A	9 X 2-1/2 X 15.0 #	11.300	N/A	10" SCH 80	45.552
4 X 3-1/2 X 5/16	N/A	N/A	12 X 1-1/2 X 10.6 #	13.715	13.715	12" SCH 80	74.526
4 X 3 X 3/8	N/A	N/A	10 X 3-1/2 X 25.3 #	18.200	18.200	14" SCH 80	98.188
5 X 3-1/2 X 5/16	N/A	N/A	12 X 3 X 20.7 #	21.500	21.500		
4 X 4 X 1/2	N/A	N/A	13 X 4 X 35.0 #	37.106	37.106		
5 X 3-1/2 X 3/8	N/A	N/A					
6 X 4 X 5/16	N/A	N/A					
6 X 3-1/2 X 3/8	N/A	N/A					
6 X 4 X 3/8	N/A	N/A					
6 X 4 X 1/2	N/A	N/A					

AVAILABLE SCANTLINGS (WHICH MEET INPUT REQUIREMENTS)							
ANGLE	**RACK SM**	**LEG SM**	**CHANNELS**	**RACK SM**	**LEG SM**	**PIPE**	**LEG SM**
7 X 4 X 3/8	N/A	N/A					
7 X 4 X 1/2	5.810	N/A					
8 X 4 X 1/2	7.490	N/A					
9 X 4 X 1/2	9.340	N/A					

Table 4 Acceptable scantling, which meets requirements from calculations.

LOOKUP CHART SECTION MODULUS AND INERTIA

SM	SCANTLING	INERTIA	SM	SCANTLING	INERTIA	SM	SCANTLING	INERTIA
0.031	1 X 1 X 1/8	0.022	0.093	RTD1.624X.625X14 GA	0.077	0.048	1/2" SCH 80	0.020
0.044	RTD 12 GA ANGLE	0.044	0.165	1-1/4 X 1/2 X 1.0 #	0.103	0.085	3/4" SCH 80	0.045
0.056	1 X 1 X 1/4	0.037	0.189	RTD1.624X.625X3/16	0.155	0.161	1" SCH 80	0.106
0.071	1-1/4 X 1-1/4 X 3/16	0.061	0.543	2 X 1 X 2.32 #	0.543	0.291	1-1/4" SCH 80	0.242
0.072	1-1/2 X 1-1/2 X 1/8	0.078	1.380	3 X 1-5/8 X 6.0 #	2.070	0.412	1-1/2" SCH 80	0.391
0.075	RTD 3/16 ANGLE	0.073	2.290	4 X 1-5/8 X 7.25 #	4.580	0.731	2" SCH 80	0.868
0.134	1-1/2 X 1-1/2 X 1/4	0.139	3.560	5 X 1-3/4 X 9.0 #	8.900	1.339	2-1/2" SCH 80	1.924
0.247	2 X 2 X 1/4	0.348	5.060	6 X 2 X 10.5 #	15.180	2.225	3" SCH 80	3.894
0.351	2 X 2 X 3/8	0.479	8.140	8 X 2-1/4 X 11.5 #	32.560	4.271	4" SCH 80	9.611
0.482	2-1/2 X 2-1/2 X 5/16	0.849	8.368	6 X 3-1/2 X 15.3 #	25.104	7.432	5" SCH 80	20.671
0.577	3 X 3 X 1/4	1.240	8.909	10 X 1-1/2 X 8.4 #	44.545	12.224	6" SCH 80	40.491
0.833	3 X 3 X 3/8	1.760	11.000	8 X 3 X 18.7 #	44.000	24.514	8" SCH 80	105.716
1.000	4 X 3 X 1/4	2.770	11.300	9 X 2-1/2 X 15.0 #	50.850	45.552	10" SCH 80	244.844
1.260	4 X 3-1/2 X 5/16	3.560	13.715	12 X 1-1/2 X 10.6 #	82.290	74.526	12" SCH 80	475.104
1.460	4 X 3 X 3/8	3.960	18.200	10 X 3-1/2 X 25.3 #	91.000	98.188	14" SCH 80	687.319
1.940	5 X 3-1/2 X 5/16	6.600	21.500	12 X 3 X 20.7 #	129.000			
1.970	4 X 4 X 1/2	5.560	37.106	13 X 4 X 35.0 #	241.190			
2.290	5 X 3-1/2 X 3/8	7.780						
2.790	6 X 4 X 5/16	11.400						
3.240	6 X 3-1/2 X 3/8	12.900						
3.320	6 X 4 X 3/8	13.500						
4.330	6 X 4 X 1/2	17.400						
4.440	7 X 4 X 3/8	20.600						
5.810	7 X 4 X 1/2	26.700						
7.490	8 X 4 X 1/2	38.500						
9.340	9 X 4 X 1/2	53.200						

******* IMPORTANT INFORMATION REGARDING THE USE OF THIS SPREADSHEET *******

ALLOWABLE STRESS IS INPUT BY THE DESIGNER TO ACCOUNT FOR ANY FACTOR OF SAFETY. FOR EXAMPLE, IF THE YIELD STRESS IS 34,000 AND A FACTOR OF SAFETY OF 2 IS DESIRED, ALLOWABLE STRESS SHOULD BE INPUT AS 17,000. G-LOADS ARE WORST CASE AT SEA CONDITIONS. IT IS ASSUMED THAT A TANKER WILL NOT EXPERIENCE A G-LOAD OF 3 SO THERE IS AN IMPLIED FACTOR OF SAFETY HERE. SCANTLINGS ARE CHOSEN BY THE MAXIMUM BENDING MOMENT ENCOUNTERED IN THREE DIFFERENT PLANES (X,Y,Z) DUE TO THE PIPE WEIGHTS AND THE LOCAL G-FORCES APPLIED. A START-UP FACTOR IS INCLUDED TO ACCOMMODATE FOR ANY ADDITIONAL FORCES INDUCED UNDER CIRCUMSTANCES SUCH AS THE STARTING UP OF THE PLANT.

Table 5 Available scantling data. (Represents the raw material stock carried by the shipyard and the section modulus and inertia data for each shape).

2.3. THE 3-D PRODUCT MODEL

The 3-D model represents the key design tool to this project. Traditionally, foundation and hangering systems have been shown as a two-dimensional overlay onto the 3-D model production information. Having all foundations and hangering systems modeled is essential to achieving major improvements in producibility. Complete 3-D modeling can provide the following benefits and outputs:

- Ensure an interference free design.

  As part of this project, a root cause analysis study was performed to determine the highest rework causes in foundation and hangering system installation. This study revealed that interference s and material inaccuracies are the highest causes of rework within production. Rework must be considered when determining the completely installed cost of any product.

- Automatic downloading of the parts from the 3-D model to the yard material control and procurement system (Bill of Material).

  This is an elemental but essential step in reducing the total installed cost. A manual material take-off from any 3-D model is 100% non-value-added. There is a huge amount of rework and non-value added tasks involved in engineering and production when employing a manual material take-off system.

- Numerically-controlled (NC) layout marking on the deck plates.

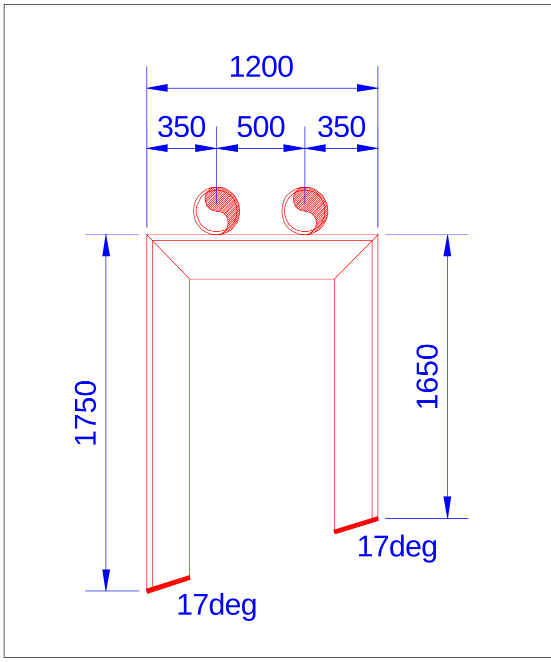
  This can be obtained by downloading information from the 3-D model to the NC burning machine tapes. This eliminates manual layout in production, which in some shipyards may be on the critical path.

- Foundation and multi-hanger system sketches with exact cut lengths can be obtained automatically.

  One key factor to reduce over all cycle time for ship construction, with regard to outfitting, is to focus on installation only and not fabrication. Fabrication should be driven back to the shops and be taken off the on-block critical path. Therefore, it is key that these stages of construction are provided with material that is available for installation and not fabrication. There can be a high degree of confidence that a part will fit in the required installation when coming from the model as opposed to free hand sketches, especially with complex parts.

  An example of this pre-fabrication is providing hangering systems, which do not require measuring and trimming to suit in the field. Hangering sketches can be done an output of the 3-D model as shown in Figure 3.

Sketch of pipe support



Material List		
L#	100*100*10	4450 mm
UB	UB1_200	2 ea
UN	UN1_200	4 ea
Paint	U2	
Position	X	FR67+500
	Y	700(STBD)
	Z	1500 ABL
Weight	325 Kg	
Name	ES_PPSPT_B01_005	

Figure 3 Pipe Support Sketch

2.4. STANDARDS

A simplified approach is to use the same parts in all standards across all trades as far as practical. The complete set of standards for foundations and hangers are included in Section 7 of the accompanying manual. The benefits are as follows:

- Production and Engineering become accustomed to fewer parts.
- Minimize hand-offs between trades.
- Stocking less parts which minimizes storage requirements.
- Vendors now have the ability to mass-produce identical parts for a lower cost.
- Elimination of labor intensive fabrication tasks.
- Minimizing labor-intensive installation tasks.
- Reduce total installed costs, which includes engineering costs, material cost, fabrication cost, and installation cost.

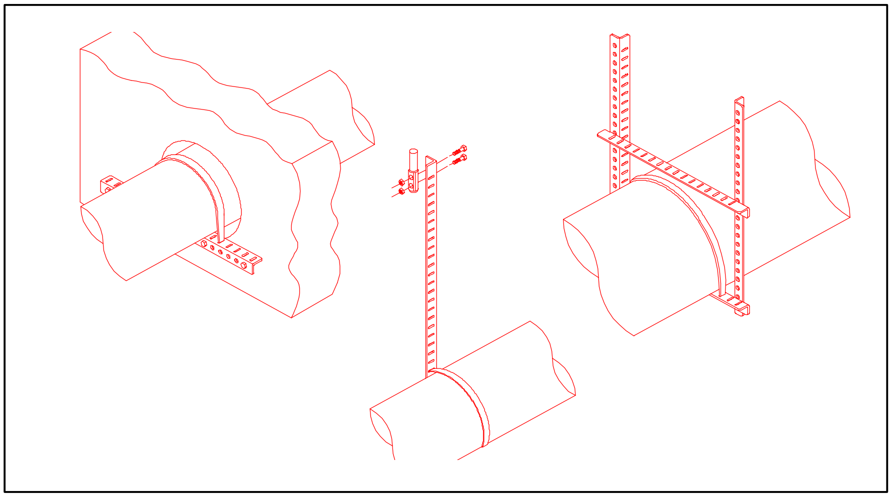


Figure 4   RT&D Interchangeable Ventilation Hangering System

The ventilation hankering system above shows the same standoff being utilized in a variety of configurations. This system is extremely flexible, easy to install, and cost effective.

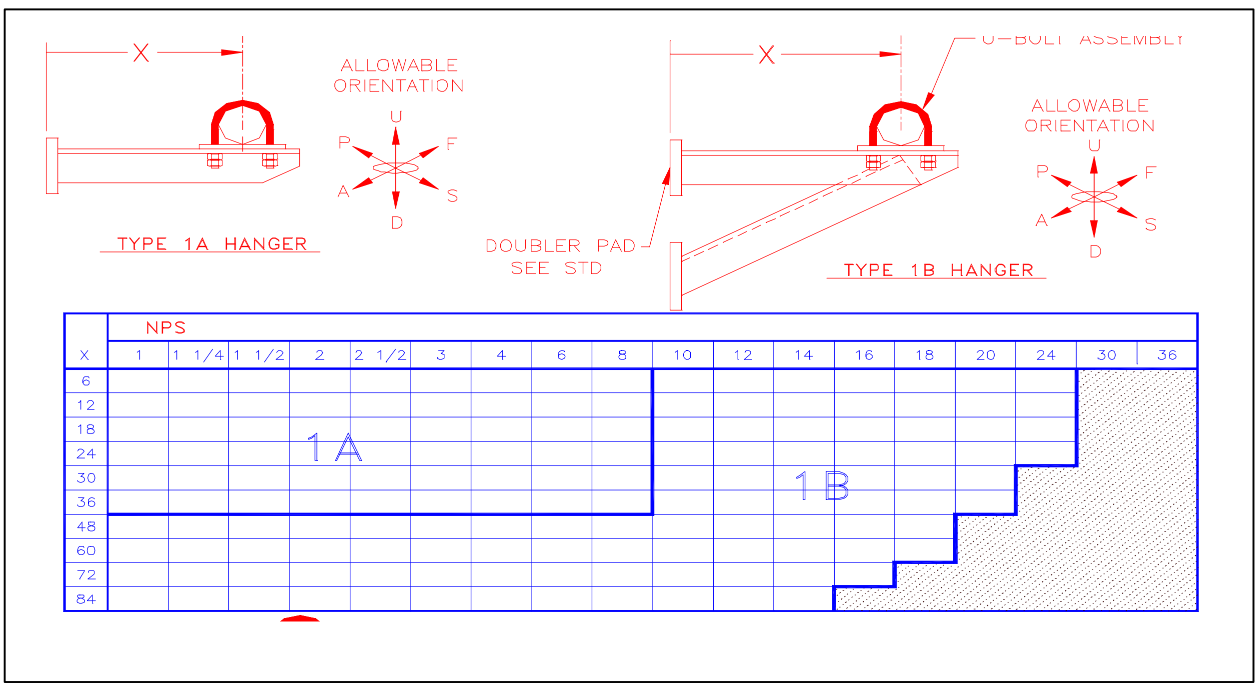


Figure 5   U-Bolt Standard (Scantlings Determined Using Spreadsheet Method)

This hanger is an excerpt from the standards shown in section 7 of the manual. The scantlings requirements were determined using the scantling selection spreadsheet also shown in section 7 of the manual.

2.5. FAMILY OF FOUNDATION TYPES

The development of revolutionary standards for H, M & E equipment and systems installations that will permit rapid modular assembly will facilitate the construction of the hull modules by reducing the labor time and cost in both the Hot pre-outfit and Cold outfit phases of construction. This exploratory research and development effort will focus on the development of techniques, methods, and standards that will facilitate the shifting of H, M & E outfit of foundations and systems installations from the labor intensive Hot pre-outfit construction practice to the considerably more efficient Cold outfit assembly line practice.

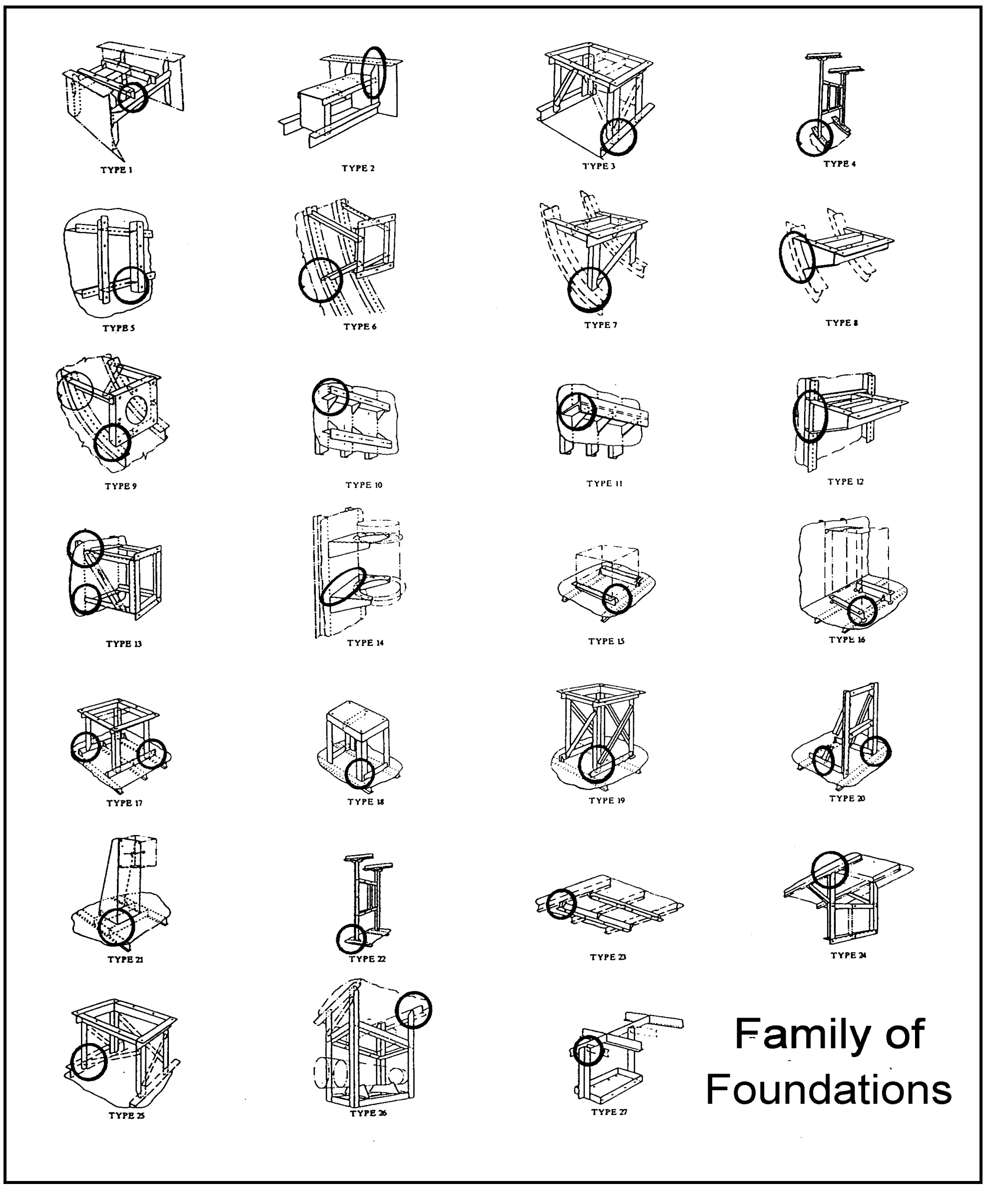


Figure 6 Family of Foundations

2.6. CONCURRENT ENGINEERING

Forming of a cross-functional team which represents all functional groups which can affect the products cost is essential to achieving the lowest possibly installed cost and to minimize sub-optimization. Defining the groups goal of achieving the lowest installed cost early and running pilots to verify predictions creates a system, which is extremely effective.

3. MANUFACTURING

3.1 RAW MATERIAL COSTS

The selection of raw material is important in that commonly used shapes should be used and applied consistently throughout the standards. A common error would be to specify an unusual shape or type of material on an engineering drawing with no thought to availability or material cost. Being cognizant of this simple fact can help hold down the cost of a ship set of standard foundation and hangering systems. For example, the raw material shown on the Hangering Scantling selection program are those carried in stock only. The user shipyard should replace their in-house stocked steel material with what is shown in the spreadsheet. An effort should be used to minimize the in-house selection. Shipyards should also be aware of the material used by their subcontractors, as it will drive up the costs if a material type is specified which is not carried in stock by the subcontractor.

3.2 FABRICATION COSTS

Various studies were conducted to investigate fabrication costs. They involved Industrial Engineering type time studies (breaking down each incremental step in the process) within the shipyard and main subcontractors. The following is a simple example of how this process was performed and the resulting reduction in fabrication times and other benefits. The figures below show the progression when applying the producibility features to a product. This is a simple example of what would appear to be an elementary way to do business. Labor-intensive standards being fabricated repeatedly without much thought to the fabrication time is common place. This change in design will also minimize the engineering work content by eliminating the lofting and simplifying the detailed design requirements. Simple producibility features, such as this, can be applied with significant results. By minimizing the production steps, fabrication time was reduced from 5.45 hours to 1.24 hours on this part.

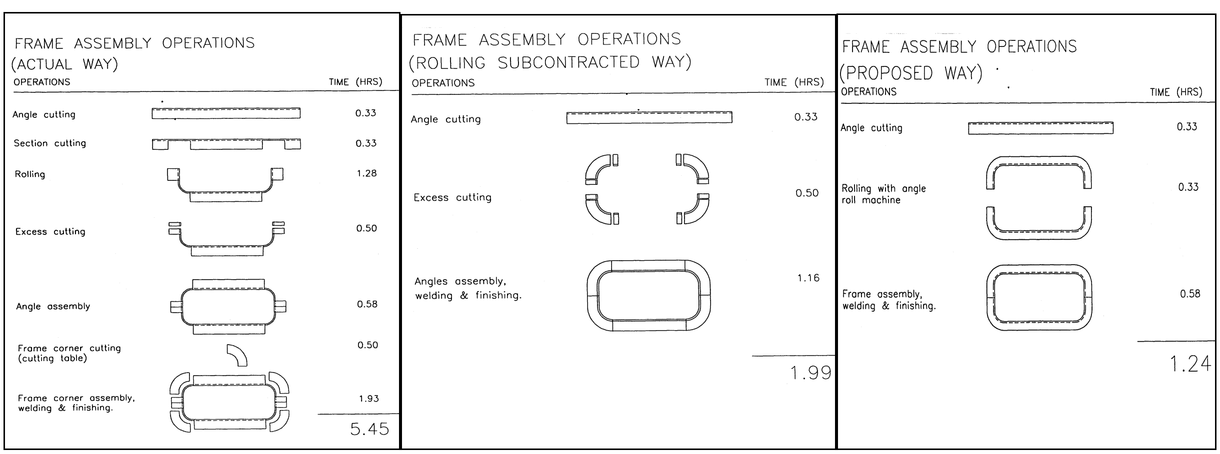


Figure 7 Foundation Frame Labor Intensive Part Easily Produced Part

4. INSTALLATION

4.1. INSTALLATION COSTS

Various studies were done as part of this NSRP project to investigate installation costs. Similarly to the fabrication time studies the complete installation process is broken down and flow-charted for identification and elimination of non-value added tasks. Below is a comparative analysis of different types of single-run hangering systems that were being evaluated for use. It is important to do real time pilot studies using a large enough quantity to be comfortable with the results. There are often many factors that may skew these results. It is important to recognize and understand these skewing factors. Running a large quantity of the proposed products through the time studies will minimize these factors. It is also important to observe the installation and take notes on key points.

The tables below show the comparative analysis technique that was used in determining the preferred installation type for inclusion into the total installed cost.

HANGER #1 INSTALLATION TASKS	SAMPLE 1 (SECONDS)	SAMPLE 2 (SECONDS)	SAMPLE 3 (SECONDS)	SAMPLE 4 (SECONDS)	SAMPLE 5 (SECONDS)	SAMPLE 6 (SECONDS)	AVERAGE (SECONDS)
HANGERS FROM PALLET TO BLOCK	63	63	63	57	47	51	57.3
CHECK PAPERWORK	142	118	137	194	201	217	168.2
CALCULATE STANDOFF LENGTH	40	23	13	13	41	27	26.2
WALK TO SAW/CUT/WALK BACK	240	147	163	117	133	141	156.8
GRIND PAINT FROM HANGER	75	75	75	75	75	75	75.0
WELD ANGLE BAR TO HANGER	250	234	278	180	201	213	226.0
CUT LINER TO SUIT	18	17	21	11	9	14	15.0
RETRIEVE HANGER FASTENERS	30	30	30	30	30	30	30.0
WELD HANGER TO DECK	83	91	76	69	87	91	82.8
INSTALL LINER	18	12	14	11	12	9	12.7
INSTALL PIPE	22	37	37	37	41	41	35.8
INSTALL HANGER TOP & FASTEN	47	68	59	88	49	53	60.7
TOTAL TIME	1028	915	966	882	926	962	946.5
						TOTAL AVERAGE TIME	15.78 MINUTES

HANGER #2 INSTALLATION TASKS	SAMPLE 1	SAMPLE 2	SAMPLE 3	SAMPLE 4	SAMPLE 5	AVERAGE
STUD LAYOUT	134	144	105	106	96	117
STUD FERRULE SETUP	23	30	22	32	45	30.4
SHOOTING STUDS/REMOVE SLAG	23	25	29	22	21	24
HANGERS FROM PALLET TO BLOCK	35	35	35	35	35	35
CHECK PAPERWORK	47	45	43	55	47	47.4
CUT STAND-OFF TO SUIT	64	47	77	47	39	54.8
REMOVE PROTECTIVE CAP	15	24	19	11	26	19
ATTACH STANDOFF TO STUD	37	49	63	35	28	42.4
CUT LINER TO SUIT	15	30	10	14	12	16.2
ATTACH HANGER HEAD TO STANDOFF	46	60	43	47	48	48.8
REMOVE PIN	5	7	6	8	5	6.2
INSTALL LINER	13	13	6	8	5	9
INSTALL PIPE	27	22	18	26	33	25.2
INSTALL PIN	19	25	35	42	19	28
		556	511	488	459	503.4
					TOTAL AVERAGE TIME	8.39 MINUTES

Figure 8 Hanger Installation Time Study Comparison Matrices

4.2. TOTAL INSTALLED COSTS DATABASE

It is recommended that databases be built containing the total installed costs that are made up from material, installation, fabrication and other such costs for future use. This database can be used as comparison data to evaluate and compare new products and installation techniques. This type of data is invaluable to eliminate any subjectivity from the product choices.

4.3. DIMENSIONAL LAYOUT FOR HANGERS

Traditionally, hangers are not dimensionally located on the drawing. Instead the centerline of the system is given on the detailed drawings. This is not a problem if the hanger is centered directly below the hanger. Hangers and the pipe, vent, and electrical systems are installed at the same stage of construction. This involves locating the pipe and determining from their where the hanger should land.

A new layout method would dimension the hangers, as opposed to the systems. From the model, locations of the hangers can be easily located on a hanger location drawing. This gives a much high degree of accuracy for hanger locations. The hangers then arrive on-block, pre-cut, for immediate installation at the Hot-Work

stage of construction. The new methodology consists of installing the system to the hanger as opposed to the installing the hanger to the system.

Another layout method consists of using the 3-D model to get automated layout. This is done by downloaded the interface between the hangers and the structure to the N.C. tapes and from there to the N.C. burning machines.

Imbedding Expert Systems within the 3-D model environment.

This has the primary structure, foundations and hangering systems all being located from the same datum. Manual layout should be minimized. When designing racking systems or foundations on the same side as the primary structure, designers should utilize the primary structure to achieve layout. A fore/aft piping rack running on the underside of the deck should use the web-frames to give height and fore/aft dimensioning from the deck, with longditudinals to determine athwartship dimension.

4.3.1. N.C. LAYOUT HANGER MARKING SYSTEM

The A and B indicators shown above in the standard are modeled as part of the hanger in the 3-D model. These coordinate points are the data that is downloaded from the model to the N.C. burning tapes and from there onto the deck plates. A hanger numbering system should be in place, which would give the worker the simple task of matching up the hanger and N.C. layout identification numbers and welding out. It is recommended that the hanger be completely fabricated for immediate installation in the field with no field fabrication. This will assist in minimizing the block outfitting times.

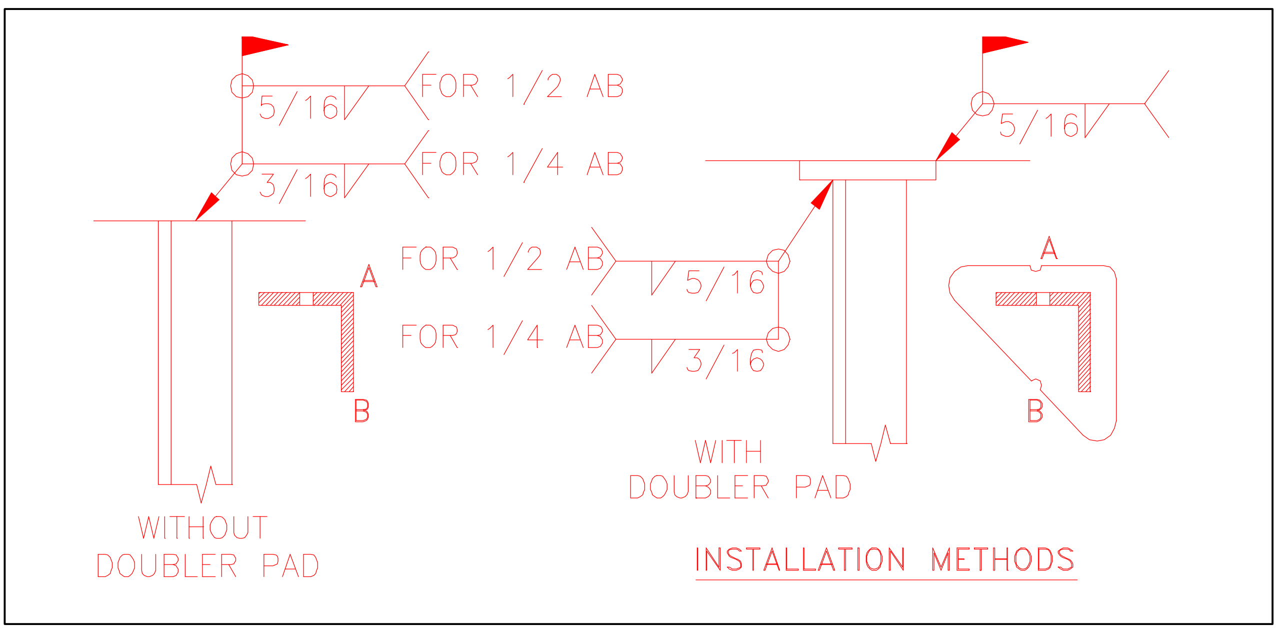


Figure 9 Hanger Layout System - 3-D Model To The Deck Plates

4.4. ATTACHMENT TECHNIQUES

The determination of which attachment technique should be used is determined mainly by which stage of construction the particular product will be installed in. A general rule of thumb is that hot work should be accomplished at the earlier stages and cold work for the later stages of construction.

During the early construction stages hot work (welding) is the primary task being performed. Therefore when it is beneficial to integrate outfitting into steel construction, welding should be adopted as the attachment technique for the outfitting products. This minimizes the amount of trades and services required at that stage and hot work damage to paint and insulation is not an issue.

During the later stages of construction hot work damage to other products becomes an issue. It is at these stages where the cold work attachment techniques should be considered for use.

4.4.1. HILTI SYSTEMS

Hilti Corporation has developed a number of fastening systems for industrial and marine applications that support the concept of quick attachment methods for shipboard use on foundations and system attachments. Their systems include Powder-Actuated Fastening, Screw Fastening Systems and Anchor systems. They have developed a channel installation system that will facilitate the lattice work system discussed previously. A description of the system components and some applications is included herewith.

Figure 10 Hilti Foundation Leg Installations This type of installation has various benefits. The panel can be used as a template to locate the stud locations. This is also a desirable method if this piece of equipment is planned to be installed after final paint.

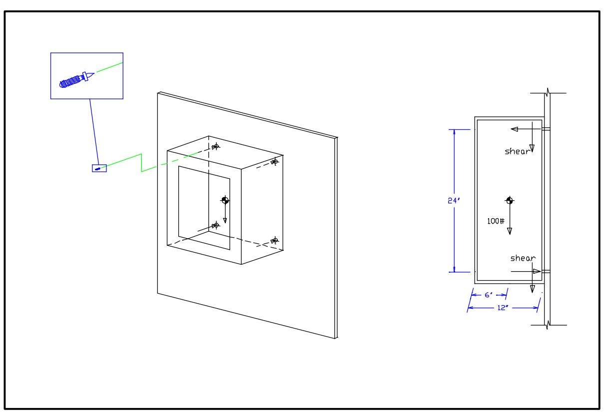


Figure 11 Typical Hilti Stud Installation

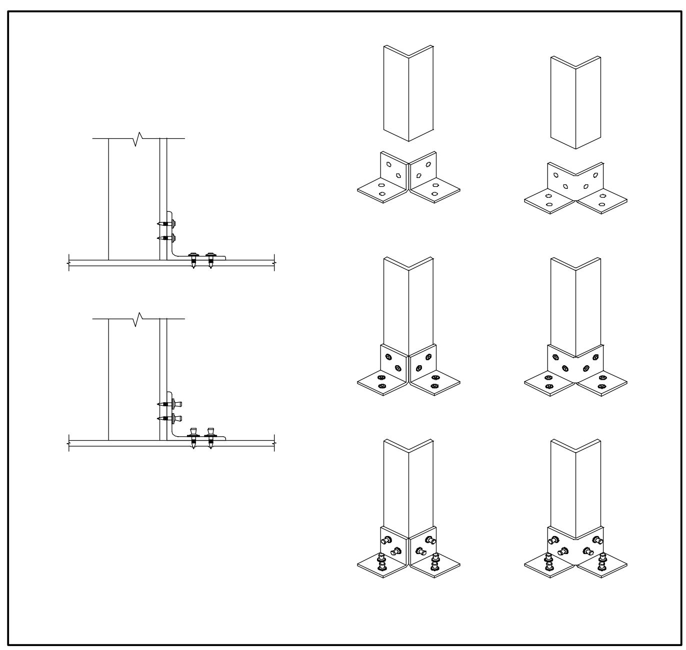


Figure 12 Stud Mounted Panel

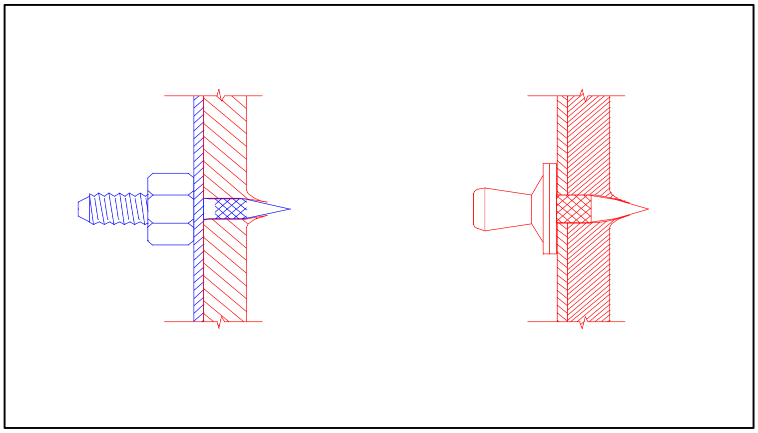


Figure 13 Typical Hilti Stud Attachments

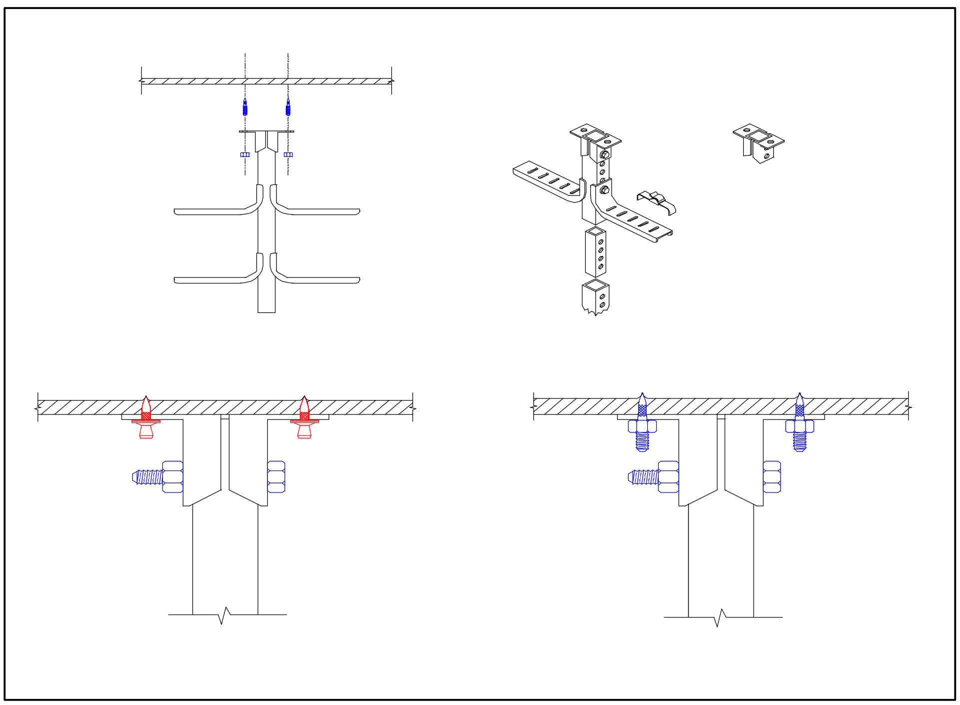


Figure 14 Hilti Stud Mounted Hanger Standoffs

4.4.2. FOUNDATION ATTACHMENT TECHNIQUES

The new techniques, methods and standards developed to suit both shop work and simplified outfit will integrate nicely with Simulation Based Design (SBD) and concurrent engineering to reduce overall engineering design time. The development of H, M&E systems installations to support a more competitive

build strategy using the revolutionary H, M&E standards will achieve significant reduction in ship construction time and costs.

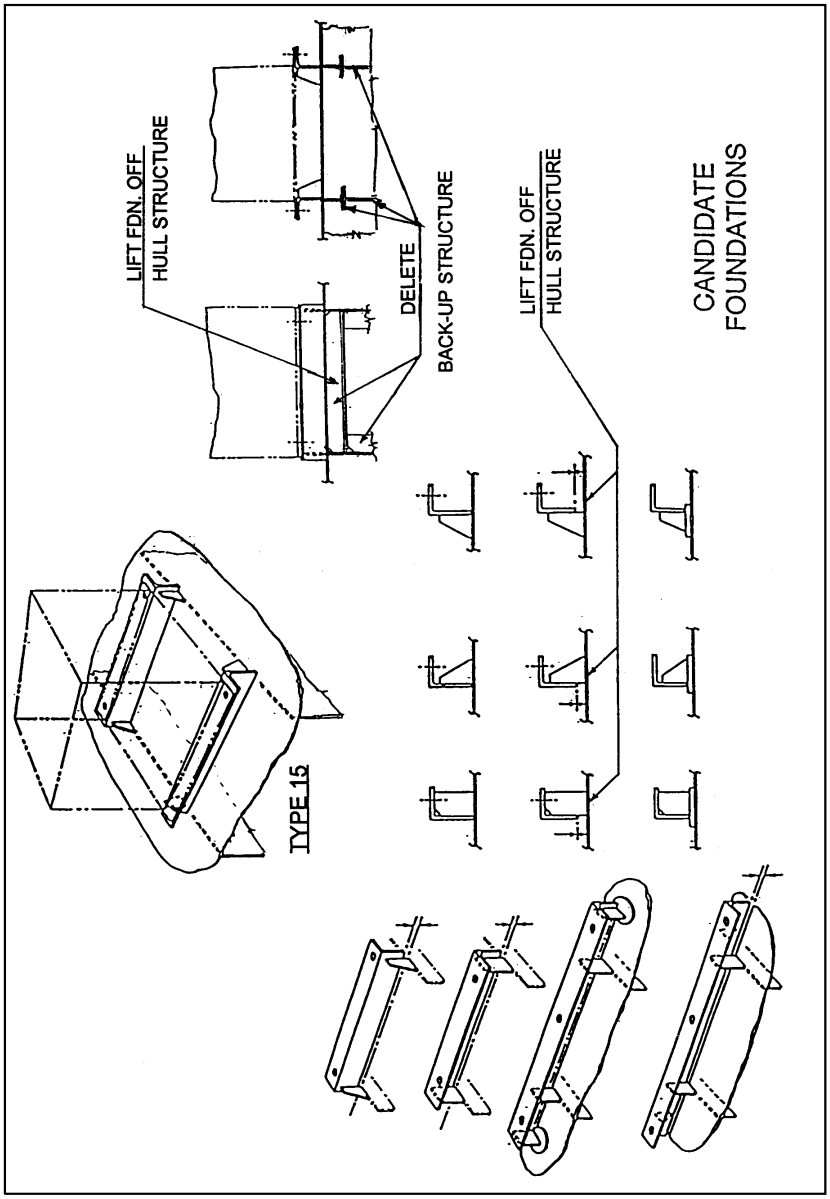


Figure 15 Alternative Foundation Attachment Techniques

4.4.3. SMART SYSTEM

Ship Modular Arrangement Reconfiguration Technology gives a high degree of interchangeability to on-board equipment installations. If smart system would be recommended when the on-board installation required the following criteria:

- Mission Flexibility.
- Number of anticipated changes to equipment in the projected ship life.

The following figures give an overview if the system with sample installations.

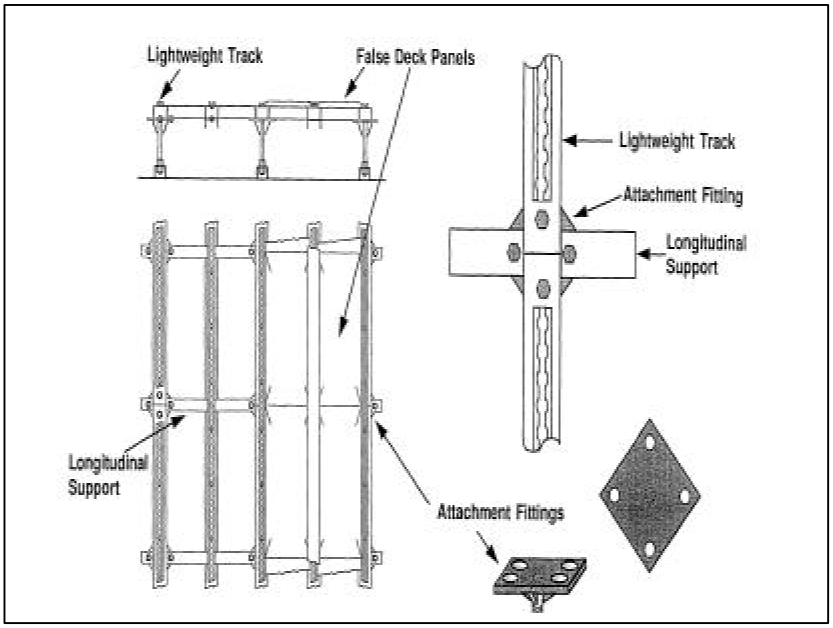


Figure 16 Lightweight "Softtrack" and False Deck Assembly

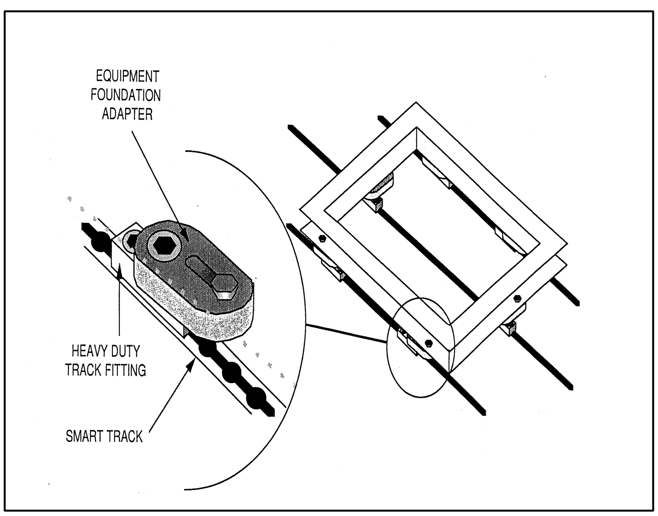


Figure 17 Medium/Heavy Weight Attachment and Fitting Assembly

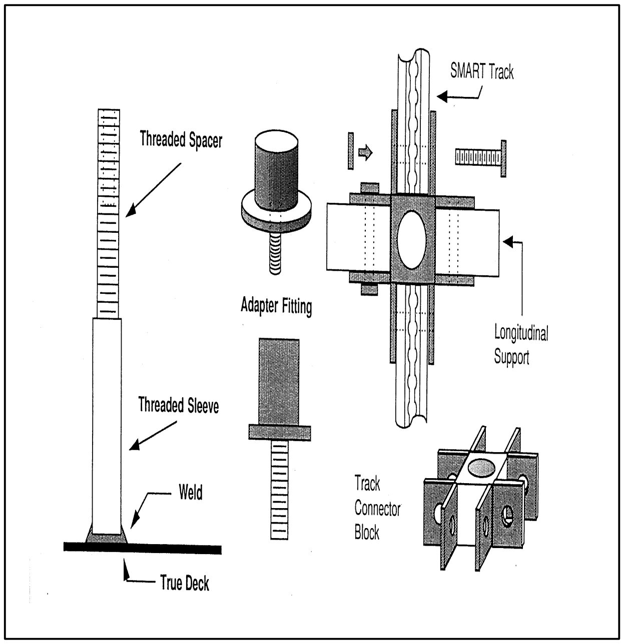


Figure 18 Typical Equipment Foundation With Track Fittings and Foundation Adapter

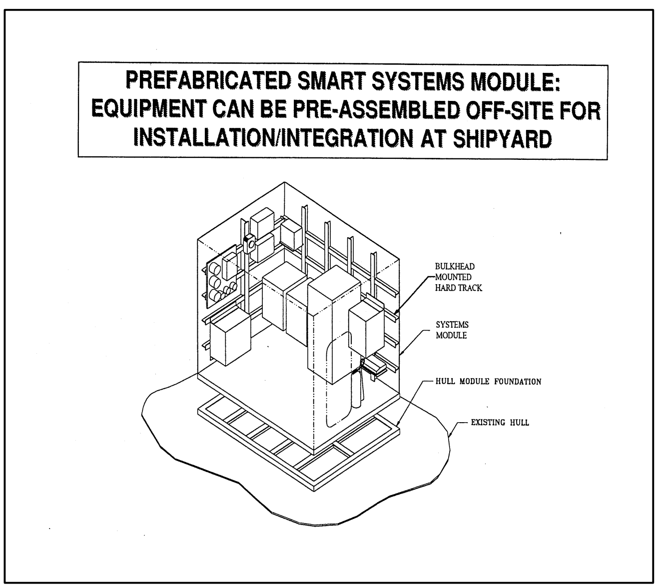


Figure 19 Prefabricated Smart Systems Module: Equipment Can Be Pre-Assembled Off-Site For Installation At Shipyard

4.4.4. TYPICAL SMART SYSTEM INSTALLATION

Determine candidate SMART deck spacing using modular track systems criteria matrix.

Perform deck/bulkhead survey to determine area & track orientation, and hard (mil. Spec.) versus soft track (cots) requirement.

Install track adapters.

Install SMART track.

Install longitudinal supports.

Install Deck panels/Filler Strips.

Install equipment foundation fittings and adapters.

Install equipment foundations and equipment.

4.5. ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

4.5.1. OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

4.5.2. BACKGROUND/APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16 of an inch. However, it may be possible to broaden the use of robots through the use of standard construction details for both structure,outfitting and equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards.

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant MAP would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness and other characteristics) in order to complete the weld or other construction sequence.

The robot with 3-D vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach Pendant will orient the robot to its work, and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvements in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for actual distortions, skewness and irregularities will usher in advanced applications for robots.

4.5.3. TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, and limitations in following prescribed tool path. Characterize state of the art in 3-D vision systems and teachable robots

2. Define parameters for the constraints on robots, standards, 3-D vision systems and teach pendant systems.

3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.

4. Select Candidate structural/ outfitting details, portable robotic systems, 3-D vision systems and teachable control systems to develop candidate applications for portable robotic systems.

5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

5. PILOT PROGRAMS

When products were considered for implementation to the standard a Pilot was run before full implementation. The pilot included collecting material costs, fabrication costs, along with doing time studies for installation. This gave a total installed cost for each product. The focus was on reducing cycle time along with minimizing total cost. Running the pilot gives a comfort level when selecting one product over another.

5.1. CENTRAL KITTING AREA

A central kitting area is required to assemble complete hanger assemblies, which are cut to suit, and deliver then ready for installation. The idea is to have the worker on-block or on-board to be installing the hangers only. Removing any cutting or assembling from the installation area which increases the throughput of the block. This in turn reduces the cycle time to build a ship.

6. CONCLUSION

The use of the standards, attachment techniques and processes for equipment foundations and hangering systems for distributive system outlined in this project will have a dramatic effect reducing the overall construction time of the ship

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